TRANSACTIONS
American Society for Steel Treating

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WINTER SECTIONAL MEETING

THE next general gathering of the members of the American Society for Steel Treating will be at the time of the Winter Sectional Meeting to be held in the City of Washington, January 20-21, 1927.

The plans and arrangements which have thus far been made by the energetic committees of the Washington-Baltimore Chapter are well under way and from all indications this meeting will be one of great value to all who attend.

On Wednesday, January 19, members will begin to gather inasmuch as on that day the newly elected national officers will hold their first business meeting of the year at the headquarters hotel, the Mayflower.

The Publication Committee of TRANSACTIONS will likewise hold a meeting on this same day for the consideration of publication matters.

At 6:30 p. m. that evening, the third Early Birds' dinner will take place, to which all members of the Society are invited. This feature was inaugurated at Buffalo last year and repeated at Hartford in the spring and proved to be a very successful innovation. Following the dinner the party will attend the theater.

The first technical session will be held on Thursday morning, January 20, and in the afternoon there will be an inspection trip. At 6:30 p. m. that evening a banquet will be held at which time a number of the most interesting addresses will be given by important personages in the Washington district.

On Friday there will be two technical sessions and one inspection trip. The technical sessions will be held in the morning and evening and an inspection trip is scheduled for the afternoon.

For those who desire to remain over until Saturday, the committee has arranged an interesting tour of the city of Washington and environs.

The tentative schedule of technical papers to be presented at these meetings is as follows:

Centrifugal Casting of Steel—Leon Cammen
Fundamental Research on Non-Metallic Inclusions in Steel—C. H. Herty, Jr.
Progress in Study of Normal and Abnormal Steel—Samuel Epstein and H. S. Rawdon
Normality of Steel—J. D. Gat
Review of the Metallurgical Activities of the Washington-Baltimore District—Emil Gathmann.
Wear Resistance of Cutting Edges of Blanking Die Parts and Shear Blades—W. J. Merten

The Mayflower will be the official headquarters and all technical sessions and committee meetings will be held there. Members and guests should make their hotel reservations as early as possible and directly with the hotel management, stating the time of arrival, the price of accommodations desired and requesting an acknowledgment from the management of their reservation.

Rates for some of the hotels are as follows:

Hotels	Single Room with Bath	Double Room with Bath	Twin Beds
Mayflower	$5 to $10	$7 to $12	$9 to $14
Willard	5 to 8	7 to 9	8 to 15
Washington	5 to 8	8 to 10	10 to 12
Raleigh	4 to 6	5 to 8	7 to 10
Harrington	3.50 to 4.50	5 to 8	7 to 8

WASHINGTON

WASHINGTON—the Nation's capital—is situated on the shores of the Potomac River and is endowed with great natural beauty of landscape. In 1790, this site was chosen by George Washington with authority from Congress to be the capital city of these United States.

In 1791, Major Pierre Charles L'Enfant, a young French engineer, who had won honor in the Revolutionary War, was appointed by George Washington to plan the city. L'Enfant formulated a most comprehensive, attractive and rational plan, capitalizing on the physical features and the natural beauty of the landscape and adapting them to his purpose. His plan was based on the French City of Versailles.

He made the Capitol and the White House the two main focal points of the city and these were the first public buildings erected.

The cornerstone of the Capitol was laid by Washington in 1793. The central portion of it is constructed of Virginia sand-

stone and the wings or extensions are of Massachusetts marble. The length of the building is about 750 feet, its width is 350 feet and it covers about 3½ acres of land. It is built upon an elevation of 97 feet above the level of the Potomac River and rises majestically above its surroundings. The dome, one of the six finest in the world, is its crowning glory. This is surmounted by the statue of Armed Liberty which is over 300 feet above the esplanade and weighs 15,000 pounds. A full-sized replica of this figure may be seen in the National Museum. The great lantern, 15 feet in diameter and 50 feet high, spreads its light over the entire city. The Capitol, always majestic and beautiful, is never more striking than when seen at night brilliantly lighted.

Adjoining the Capitol grounds are those of the Library of Congress facing west on First Street. This is said to be the finest library building in all the world. It is of Italian Renaissance architecture and was completed in 1897. It is three stories high and its exterior is constructed of white New Hampshire marble. It contains over three million books and prints.

This is not a public library in the strictest sense of the word, but was constructed primarily for use of the members of the congress, yet anyone may have access to all the stored up knowledge of the ages if he chooses to avail himself of the opportunity. Here may be seen books from all over the world, historical documents of great value, etc.

In 1814 the British burned the Capitol and White House. The walls of the White House remained standing and when it was rebuilt the stained walls were painted white,—hence the name. Here may be seen historical relics, portraits of presidents, gifts from foreign lands, china used by the various presidents, etc. Here may be seen the famous "Blue Room", where official receptions and balls are held, the red room, the green room, the official dining room and other state rooms together with the president's private apartments.

South of the White House stretches a magnificent expanse of lawn where the Washington children engage in the great sport of egg-rolling on Easter Monday.

To the southwest are located a group of splendid buildings, some of the finest in Washington, the Corcoran Art Gallery which contains a fine collection of art treasures; the Red Cross Build-

ing; Continental Hall which was built by the Daughters of the American Revolution; and the Pan American Union built for the express purpose of fostering friendly relations between the 21 American Republics.

North of the White House is Lafayette Square, one of the largest and probably the most beautiful square in the city. Here may be seen the memorial to the foreign soldiers who aided America to gain her independence.

Just behind the White House on the west is a five story building covering 4½ acres which houses the State and War Departments.

Beautiful vistas stretch westward from the Capitol down the broad green of the Mall. This park, about four blocks wide, extends to the banks of the Potomac. Here one may see a splendid array of public buildings, such as the National Museum, Smithsonian Institute, the Department of Agriculture,—and in the distance rises the great white shaft of Washington Monument, 555 feet high.

On the edge of Potomac Park just to the southeast of Washington Monument is the Bureau of Engraving and Printing where paper money, government bonds, postage and revenue stamps,etc., are printed. Here one may see every operation in the making of paper money with the exception of the actual engraving of the plates.

The government printing office in which are printed the Congressional Records and other publications from type is in another quarter of the city on North Capitol Street.

South of the Capitol at the point where the Anacostia River flows into the Potomac are the Washington barracks and the United States War College. About one mile up the Anacostia River is the United States Navy Yard where guns are made for warships.

Here may be seen Long Tom, a 42 pound cast-iron gun of the 1786 vintage. Here too one may see big guns and little guns; ancient guns and modern guns; guns from Tripoli and Algiers; guns used in the Revolutionary War, the War of 1812, Mexican, Civil and the World War.

There are many buildings, both public and private, to which attention should be given, but owing to limited space it is im-

possible to even name them all. Nor is it possible to describe the magnificent interiors of these splendid buildings in which the business of running the greatest nation in the world is carried on.

But mention should be made of the wonderful educational facilities afforded in this great city. Probably no other city in the world has such wonderful facilities for carrying on research work in all subjects known to man as has the City of Washington. One of the most notable of these organizations is the Bureau of Standards. Men of scientific minds and training will marvel at the amount of research which is being carried on both at the Bureau of Standards under the direction of Dr. George K. Burgess and at the National Academy of Sciences which organization was made possible by an endowment of $5,000,000 by the Carnegie Corporation in 1919. Its primary purpose is to promote the progress of science and research for the welfare of this great nation and of the world.

Perhaps it would be of interest to know that there are over sixty different bureaus in the government dealing with the subject of business. The work of the organizations pertaining to the interrelation of industries such as automobile, fisheries, radio, aviation textiles, insurance, iron, steel, coal, etc. is interesting and instructive.

The tremendous amount of detail work performed in connection with the government of this country staggers the imagination. It is beyond individual comprehension.

It is here in this city of cities that the sectional meeting of the American Society for Steel Treating will be held on January 20-21.

NEW A. S. S. T. GROUP

ON Monday, October 25, a new group of the A. S. S. T. was organized at Binghamton, N. Y. It is known as the Southern Tier Group and it includes members from the territory surrounding the towns of Binghamton, Cortland, Endicott, Elmira, N. Y.,Athens and Scranton, Pa. The term "Southern Tier" is a colloquialism which in New York and Pennsylvania is used to designate the towns which lie along the border of the two states.

A dinner was held at the Arlington Hotel, Binghamton, at which there were 42 present. This group enjoyed a fine dinner and then proceeded to perfect a temporary organization as fol-

lows: Chairman, James Sturrock, Jr., Ingersoll Rand Co., Athens, Pa.; Vice-chairman, B. M. Stannard, Brewer Titchener Corp., Binghamton, N. Y.; Secretary, Walter H. Ogden, 11 Rotary Ave., Binghamton, N. Y.; Treasurer, H. G. Kent, Binghamton Light, Heat and Power Co., Binghamton, N. Y.; Executive Committee: John Le Valley, Ingersoll Rand Co., Painted Post, N. Y.; M. P. Ferguson, Eclipse Machine Co., Elmira, N. Y.; R. B. Baker, Endicott Forging & Manufacturing Co., Endicott, N. Y.; Chas. Kail, A. & J. Manufacturing Co., Binghamton, N. Y.; Dan Cook, Maydole Hammer Co., Norwich, N. Y.; F. W. Taft, Security Mutual Bldg., Binghamton, N. Y.; and Miles O. Snyder, Willys Morrow Co., Elmira, N. Y.

During the course of the evening the formal charter was presented to the organization and the members nominated as temporary officers were made permanent for one year.

Following the organization session George A. Richardson of the Bethlehem Steel Company showed films on the "Making and Processing of Steel". Mr. Richardson supplemented his moving pictures with an interesting descriptive explanation which lead to a lively disucession.

The next meeting of the Southern Tier will be held at Elmira, early in December. It is the idea to rotate the meetings of the group from city to city, thereby reducing distance to a minimum and serving the membership to the greatest advantage.

The men who compose this group are most enthusiastic and interested. Though separated by considerable distances they possess the spirit that wins and assures success. The entire membership of the A. S. S. T. welcomes the Southern Tier Group and wishes it well.

THIS issue of TRANSACTIONS completes Volume X which covers the period from July, 1926, through December, 1926. Volume XI will include the period from January, 1927, through June, 1927. The index for Volume X is now ready and may be secured upon request.

Those desiring to have their loose copies of Volume X bound in accordance with the style used in binding Volumes I-IX inclusive, may do so by forwarding them to the executive offices of the Society, 4600 Prospect Avenue, Cleveland, together with $2.00, and they will be bound and returned promptly.

THE IRON-MOLYBDENUM SYSTEM

By W. P. Sykes

Abstract

This paper describes the carbon free alloys of iron and molybdenum and includes the equilibrium diagram of this system as determined from fusion temperatures, heat treatments and a study of the accompanying microstructures.

Notable features of the system include a eutectic at 36 per cent molybdenum melting at 2625 degrees Fahr. (1440 degrees Cent.), a glass-hard inter-metallic compound, Fe_3Mo_2 at 53.4 per cent molybdenum, and appreciable solid solubility increasing with rise in temperature, at either end of the system.

The temperature-solubility relations make possible the development of a secondary hardness by aging a supersaturated solid solution at 1112 to 1292 degrees Fahr. (600 to 700 degrees Cent.). This hardness is equal to that of high speed steel and persists at temperatures considerably higher.

The critical point Ar_4 is lowered from 2550 to 2245 degrees Fahr. (1400 to 1230 degrees Cent.) and Ar_3 is raised to 1795 degrees Fahr. (980 degrees Cent.) by the addition of 3 per cent of molybdenum to pure iron.

With a molybdenum content greater than 3½ or 4 per cent the iron exists in the body-centered crystal lattice at all temperatures below the melting point.

EXPLORATORY work in the field of carbon-free iron alloys revealed certain features in the alloys of iron and molybdenum which warranted a more complete investigation of this system.

Appreciable solubility in the solid at either end of the series, a minimum fusion temperature suggestive of a eutectic, and the glass hardness of the alloys near the central portion of the composition range were among the first recognized features of the system.

Materials

Both the iron and molybdenum metals used in the preparation of the alloys were in powder form. For alloys containing more than 20 per cent of iron the metal powders were mixed directly.

A paper presented before the eighth annual convention of the Society, held in Chicago, September 20 to 24, 1926. The author, W. P. Sykes, is metallurgical engineer, Cleveland Wire Works, Incandescent Lamp Department, General Electric Company, Cleveland.

In forming the alloys richer in molybdenum than 80 per cent, the oxides of iron and molybdenum were mixed and reduced together in order to bring about uniform distribution of the iron.

The iron was obtained by hydrogen reduction of ignited oxalate, previously precipitated from a solution of ferrous sulphate. This iron powder contained from 0.1 to 0.2 per cent iron oxide and less than 0.005 per cent carbon. The molybdenum metal powder, likewise hydrogen-reduced, was of the grade used in the manufacture of small wire for lamp filament supports and thin-rolled sheets. This material is about 99.8 per cent pure molybdenum and contains no carbon.

After mixing by tumbling, the metal powders, in the desired proportions, were formed under pressure of some 20 tons per square inch, into rods ½″ x ½″ x 10″.

To form the alloys without contamination, sections of the pressed rods were placed on alundum slabs and heated in an alundum tube wound with a tungsten resistor and packed in heat insulating material. While the resistor was heated, a stream of hydrogen was continually passed through the tube as well as through the case containing it, thus protecting from oxidation both the winding and the material within the tube.

This type of furnace is used commercially in the process of working tungsten and molybdenum. It will operate at a temperature of 2730 to 2910 degrees Fahr. (1500 to 1600 degrees Cent.) for several days and for shorter periods at temperatures as high as 3272 degrees Fahr. (1800 degrees Cent.). Above the latter temperature the alundum tube softens rapidly and collapses.

In this furnace complete fusions were made of iron molybdenum alloys containing up to 60 per cent molybdenum. To completely fuse an alloy richer in molybdenum than 60 per cent, it was necessary to heat the rod by passing current through it, the rod being mounted between water-cooled contacts and protected from oxidation by a hydrogen atmosphere.

Temperature Determinations

The greater part of the temperature measurements above 2550 degrees Fahr. (1400 degrees Cent.) were taken with an optical pyrometer, supplemented by a rare metal couple with potentiometer and galvanometer in certain ranges where greatest accuracy was desirable.

The block of pressed metal to be fused was first heated for several hours at about 2550 degrees Fahr. (1400 degrees Cent.) in the reducing atmosphere of the furnace described above. This operation insured thorough diffusion and consequently prevented any subnormal or local fusion, especially in the molybdenum-rich compositions. After this period of heating the alloy as yet unfused was placed on a section of alundum tube; over this was set an alundum hood with an opening towards the observer through which the telescope of the pyrometer could be focused on the inside wall of the hood and just behind and above the specimen.

Beginning at about 2550 degrees Fahr. (1400 degrees Cent.) the temperature was increased at the rate of approximately 1 degree Cent. per minute. The first liquid formed appears in sharply defined black spots on the surface, or more often black lines at the edges of the block of metal. This dark area is presumably the reflection of the relatively dark open end of the furnace tube. Several such determinations of the melting point of pure iron were in agreement within ± 3 degrees Cent. The fusion temperature of pure nickel under like conditions was also noted.

In the case of alloys the first appearance of fusion was considered to mark the solidus temperature for that composition under observation. The liquidus, or temperature of complete fusion was less definitely marked. However, by raising the temperature through the fusion range at a rate as low as 10 degrees Cent. per hour and noting the point at which the surface of the melt became completely convex the liquidus temperature could be duplicated for a given composition to within ± 6 degrees Cent. These observations were supplemented by microscopic examinations of the specimens, in which any unfused material could be identified.

Equilibrium Diagram

The equilibrium diagram of the system iron-molybdenum as constructed from temperature determinations and microscopic examination of alloys of the system is shown in Fig. 1.

With the addition of molybdenum the melting point is progressively lowered from 2740 degrees Fahr. (1532 degrees Cent.), that of pure iron, to 2625 degrees Fahr. (1440 degrees Cent.), the melting point of the eutectic of the composition 64 per cent iron and 36 per cent molybdenum, indicated at C in the diagram. At

1440 degrees Cent. iron will hold in solid solution about 24 per cent of molybdenum.

Iron-molybdenum alloys, containing 24 per cent or less of molybdenum when quenched from the solidus temperature will present under the microscope but a single phase, the large polyhedral grains of the solid solution, Fig. 2. The range in composition from pure iron to 3 per cent molybdenum, because of certain special features, will be described later in detail.

When an alloy of iron and 24 per cent or less of molybdenum is cooled from near the solidus to room temperature at a moderate

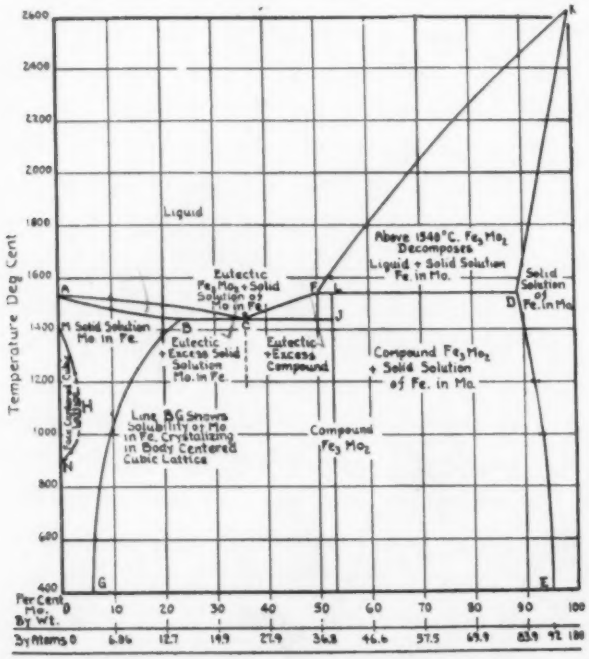
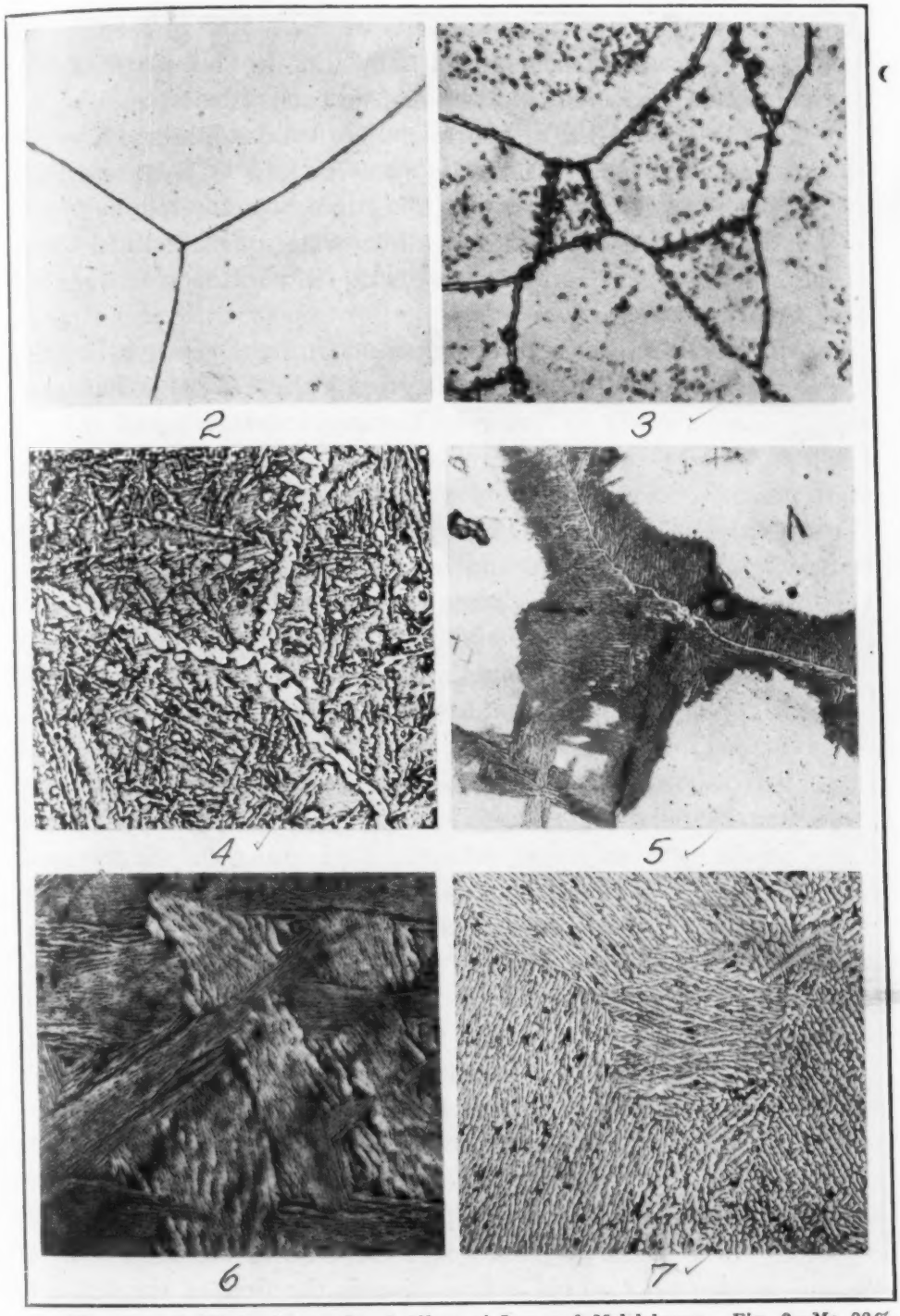


Fig. 1—Equilibrium Diagram of the Iron-Molybdenum System.

rate, a second phase appears. This is not attacked by the etching solution, 10 per cent nitric acid in alcohol, and is first observed as an intergranular network. With less rapid cooling rates this precipitate develops within the grains first as a shower of small globules, Fig. 3. Upon still slower cooling, the precipitate tends to assume a needle-like form somewhat crystalline in appearance, Fig. 4.

This second phase seems to be the compound Fe_3Mo_2 containing 53.42 per cent of molybdenum by weight, which is found to be the sole constituent of an alloy of that composition formed by pro-



Figs. 2 to 7—Photomicrographs of Alloys of Iron and Molybdenum. Fig. 2—Mo 22%, Fe 78% Water Quenched from 1425° C. Fig. 3—Mo 22%, Fe 78% Cooled in 30 Seconds from 1425° C. to Room Temperature. 500x. Fig. 4—Mo 22%, Fe 78% Cooled in 1 Hour from 1425° C. to Room Temperature. 250x. Fig. 5—Mo 30%, Fe 70% Eutectic Plus Solid Solution of Mo in Fe. Fused and Water Quenched from 1435° C. 200x. Fig. 6—Eutectic. Mo 35%, Fe 65% Fused, Cooled in 5 Minutes from 1475° C. to 1430° C. and Water Quenched. 800x. Fig. 7—Eutectic. Mo 35%, Fe 65% Fused and Cooled to Room Temperature in 30 Minutes. 100x.

longed heating at 2640 to 2730 degrees Fahr. (1450 to 1500 degrees Cent.) It is given the name iron molybdide in view of the similar compound Fe_3W_2 which is known as iron tungstide.

The line BG in Fig. 1 represents the solid solubility of molybdenum in iron at temperatures between 750 and 2625 degrees Fahr. (400 and 1440 degrees Cent.) This line was located by microscopic examination of a series of alloys water-quenched after heating for periods of 5 hours or longer at temperatures between 400 and 1425 degrees Cent.

Any precipitation of the compound brought about by heating a quenched alloy at 930 or 1110 degrees Fahr. (500 or 600 degrees Cent.) can be easily detected by the rapid darkening of the polished surface by the etching reagent. While diffusion in the solid state must of necessity be very slow at the lower temperatures, no signs of precipitation could be noted in an alloy containing 6 per cent molybdenum after holding for 50 hours at 1110 degrees Fahr. (600 degrees Cent.). This same treatment, however, developed a precipitate in a 7 per cent molybdenum alloy.

As the molybdenum content increases above 24 per cent the eutectic appears in correspondingly greater quantities. This eutectic is seemingly made up of the compound Fe_3Mo_2 and the saturated solid solution of molybdenum in iron. In alloys quenched from just below the 2625 degrees Fahr. (1440 degrees Cent.) it exists as an extremely fine network, Fig. 5 and 6. Slower cooling produces a distinctly lamellar structure in which the alternating plates of compound and solid solution can be readily identified, Figs. 7 and 8.

As the molybdenum content rises above 35 per cent massive areas of the compound share the field with eutectic Figs. 9 and 10. The alloy containing 53 per cent molybdenum, after heating at 2640 to 2730 degrees Fahr. (1450 to 1500 degrees Cent.) for 5 hours or longer appears to consist of but one phase. Presumably this is the compound Fe_3Mo_2, in which the exact percentage of molybdenum is 53.42. An alloy of this composition is decidedly porous, due seemingly to a volume shrinkage accompanying the formation of Fe_3Mo_2 in the solid. This composition is the first in the series to show no attraction for a compass needle, thus indicating the absence of any free iron.

The most satisfactory etching reagent found thus far for the

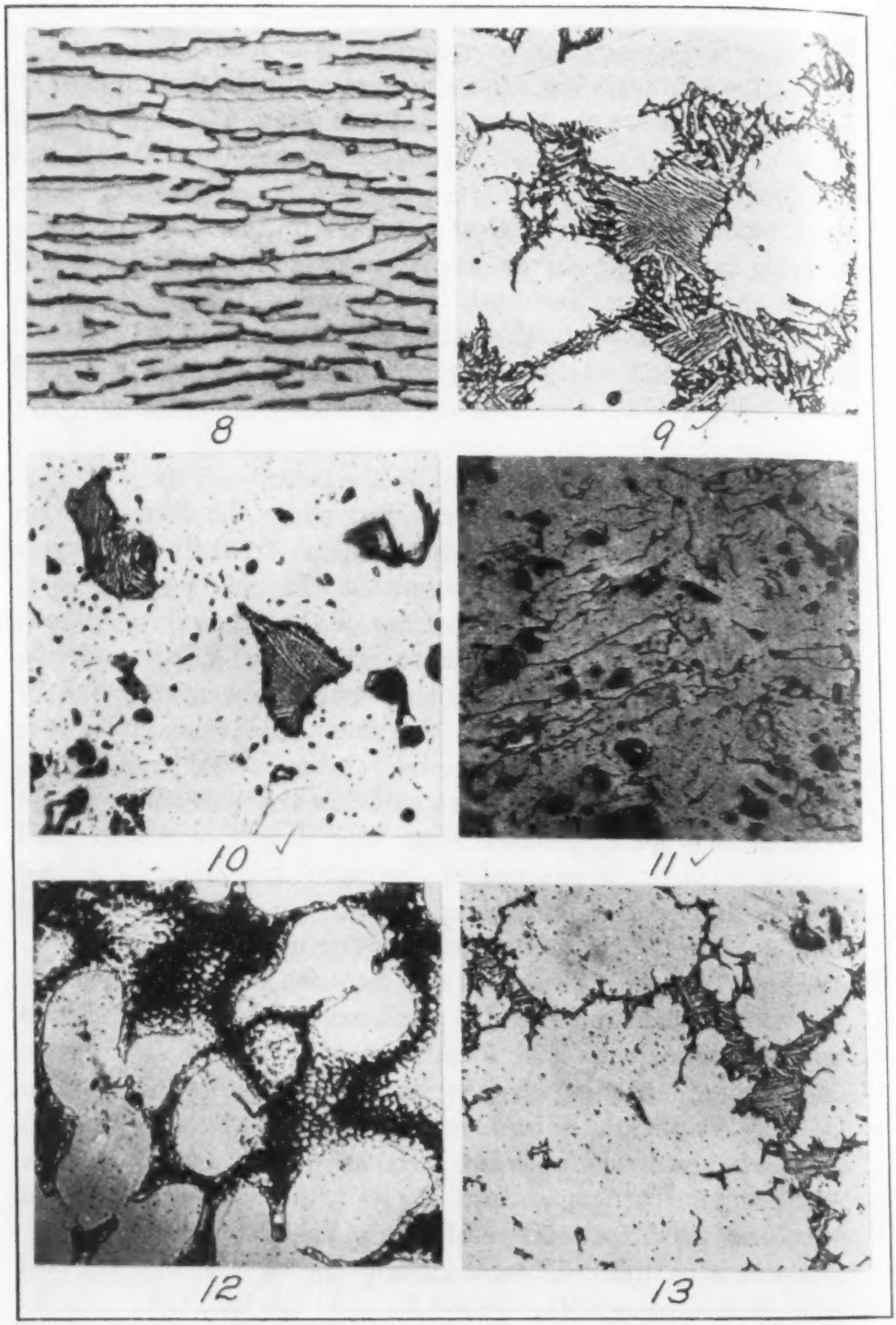
compound is a 30 per cent solution of sulphuric acid to which has been added 5 per cent of concentrated nitric acid. This reagent develops the faint and irregular lines noticeable in the micrograph of Fig. 11, which are characteristic of this phase wherever present.

The compound, in alloys within the range 50 to 90 per cent molybdenum, when heated above a temperature of about 2800 degrees Fahr. (1540 degrees Cent.) begins to fuse. In reality a decomposition sets in at this temperature, indicated by the line FLD in the diagram, resulting in two new phases. One phase, the iron-rich liquidus follows the line FK in composition. The second phase is a solid solution of iron in molybdenum which at 2800 degrees Fahr. (1540 degrees Cent.) contains about 11 per cent of iron.

A specimen consisting wholly of the completely formed compound, when heated for 10 minutes just above the decomposition temperature and quenched in water, suggests from its microstructure the mechanism of this decomposition. In such a section, Fig. 12, can be noted the large white areas of the original compound. During the process of decomposition these areas must gradually transform into the molybdenum-rich solid solution surrounded by the liquidus iron-rich phase. In the photomicrograph under consideration the molybdenum-rich solid solution would seem to appear both as a crust surrounding the original compound and also as small islands quite detached from these larger masses of solid compound. The areas occupied by the iron-rich liquidus have been completely dissolved in the etching operation, necessarily severe in order to develop the outlines of decomposing material.

A light etch will develop in the iron-rich areas the structure of the iron-molybdenum eutectic as shown in Fig. 13. A certain amount of this eutectic will form from the iron-rich liquidus in cooling as the composition changes along the line KFC. The quantity of such residual eutectic will depend upon the available supply of iron, and this in turn upon the speed at which the alloy has been cooled through the temperature range in which the compound rapidly forms from the solid and liquid phases.

If such a partially decomposed alloy be allowed to cool from 2840 to 1830 degrees Fahr. (1560 to 1000 degrees Cent.) in 30 minutes the reaction will have proceeded so far as to almost completely reform the compound, Fig. 14. The specimen in this con-



Figs. 8 to 13—Photomicrographs of Alloys of Iron and Molybdenum. Fig. 8—Eutectic. Mo 35%, Fe 65%, Cooled from the Melt to Room Temperature in 30 Minutes. 2000x. Fig. 9—Eutectic Plus Compound Fe_2Mo_3, Mo 45%, Fe 55% Cooled in 1 Hour from 1600° C. to Room Temperature. 200x. Fig. 10—Compound Fe_2Mo_3 Plus Small Amount of Eutectic. Mo 51%, Fe 49%. 200x. Fig. 11—Compound Fe_2Mo_3. Mo 53%, Fe 47% Formed by Heating 6 Hours at 1450° C. to 1500° C. Dark Areas are Shrinkage Cavities. Etched in Mixture of Sulphuric and Nitric Acids. 200x. Fig. 12—Mo 53%, Fe 47%. First Stages of Decomposition of Fe_2Mo_3, After Heating Compound 10 Minutes at 1550-1560° C. Water-Quenched. Heavy Etch. 300x. Fig. 13—Mo 53%, Fe 47%. Completely Fused, Cooled from 1650 to 1200° C. in 2 Minutes and Quenched. Light Etch. 300x.

dition does not affect the magnetic needle, while after quenching from 2840 degrees Fahr. (1560 degrees Cent.) the needle is strongly attracted. Any alloy in the range between 54 and 89 per cent of molybdenum as quenched from just under 2800 degrees Fahr. (1540 grees Cent.) exhibits in microstructure, a conglomerate made up of areas of Fe_3Mo_2 and areas of molybdenum-rich solid solution, Figs. 15 and 16.

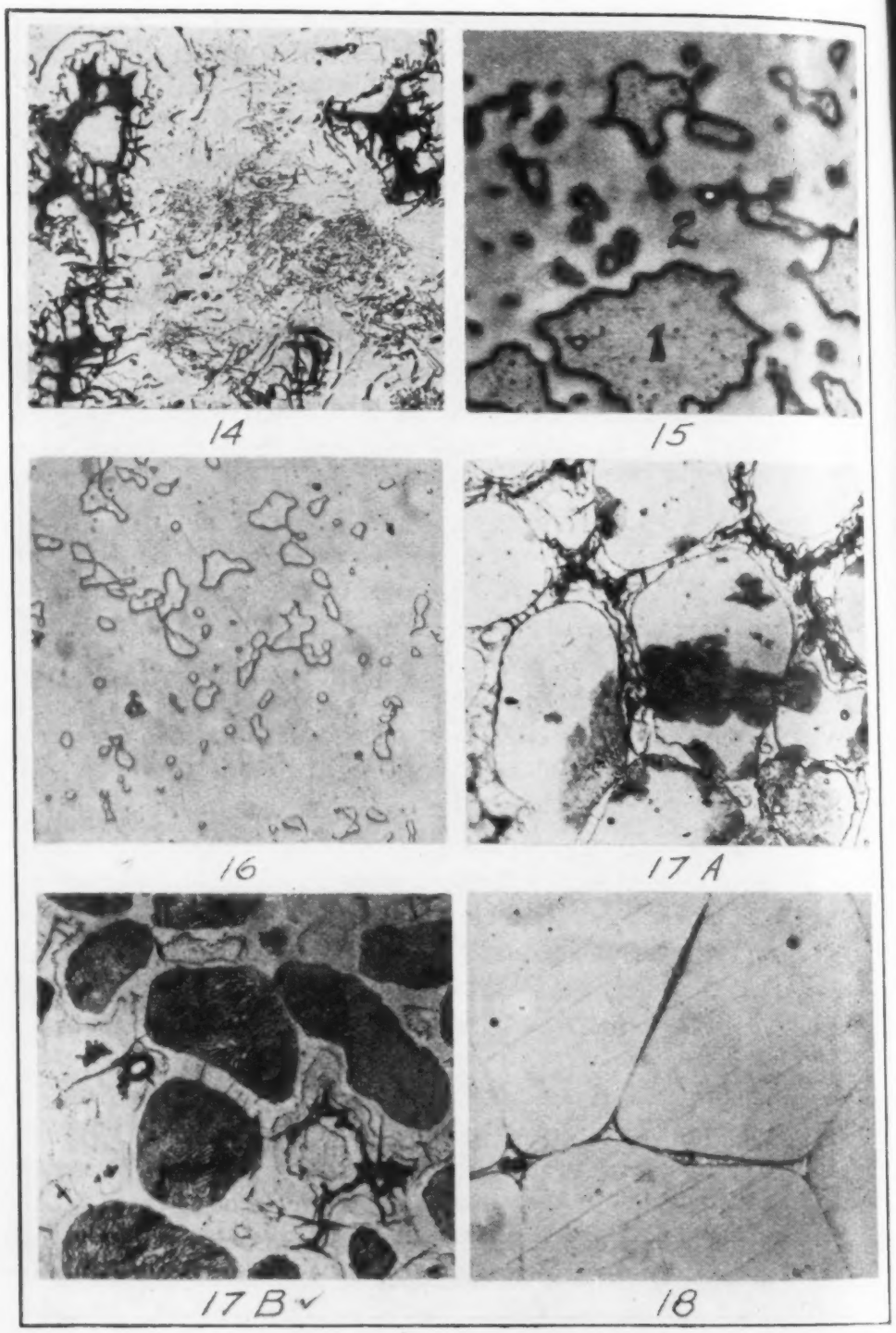
If the alloy has not been heated above 2800 degrees Fahr. (1540 degrees Cent.) about 11 per cent of iron, and when quenched scattered more or less uniformly throughout the matrix of solid solution. Upon heating at a temperature well above 2800 degrees Fahr. (1540 degrees Cent.), say at 2910 degrees Fahr. (1600 degrees Cent.), the liquidus phase resulting from the breaking up of the compound will tend to surround the grains or areas of solid solution, Figs. 17 and 18.

Molybdenum will hold in solid solution at 2800 degrees Fahr. (1540 degrees Cent.) about 11 per cent of iron, and when quenched from this temperature alloys containing less than this amount of iron will show the single phase of solid solution, Fig. 19.

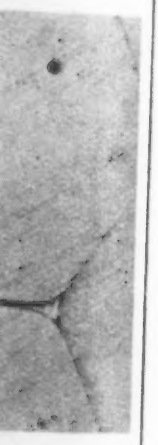
The solubility of iron in molybdenum decreases as the temperature is lowered until at room temperature only about 5 per cent is retained in solution. This is represented by the line DE in the equilibrium diagram. Upon slow cooling a molybdenum-rich solid solution from 2730 degrees Fahr. (1500 degrees Cent.) the excess iron is precipitated in the form of globules of Fe_3Mo_2 as shown in Fig. 20. The particles of precipitated compound tend to assume an elongated or fingerlike outline when the alloy has been slowly cooled from above 2800 degrees Fahr. (1540 degrees Cent.) and especially in alloys containing considerable excess iron, as illustrated by Figs. 17B, 21, and 22.

That this elongated form of precipitate is characteristic of high temperature is illustrated in Fig. 26B.

At 3180 degrees Fahr. (1750 degrees Cent.) the compound in this alloy had been largely decomposed, but during the slow cooling to 2640 degrees Fahr. (1450 degrees Cent.) has formed again almost completely, while between 2800 and 2640 degrees Fahr. (1540 and 1450 degrees Cent.) the quenching temperature, a well developed precipitate has formed in the areas of molybdenum-rich solid solution along the line DE.



Figs. 14 to 18—Photomicrographs of Alloys of Iron and Molybdenum. Fig. 14—Mo 53%, Fe 47%. Compound Reformed After Partial Decomposition. Heated 10 Minutes at 1560° C. and Cooled in 30 Minutes to 1000° C. 200x. Fig. 15—Mo 82%, Fe 18%. Water Quenched from 1530° C. (1) Compound Fe_3Mo_2, (2) Solid Solution of Fe in Mo. 500x. Fig. 16—Mo 87.5%, Fe 12.5%. Water Quenched from 1530° C. Aged 15 Hours at 775° C. 500x. Fig. 17A—Mo 70%, Fe 30%. Heated at 1600° C. for 5 Minutes. Water Quench. Cooled to Black Heat in About 5 Seconds. 500x. Fig. 17B—Mo 70%, Fe 30%. Heated at 1600° C. for 5 Minutes. Cooled to Black Heat in About 30 Seconds. 500x. Fig. 18—Mo 88%, Fe 12%. Cooled from 1700° C. to 1530° C. in 30 Minutes. Held at 1530° C. for 30 Minutes and Water Quenched. 500x.



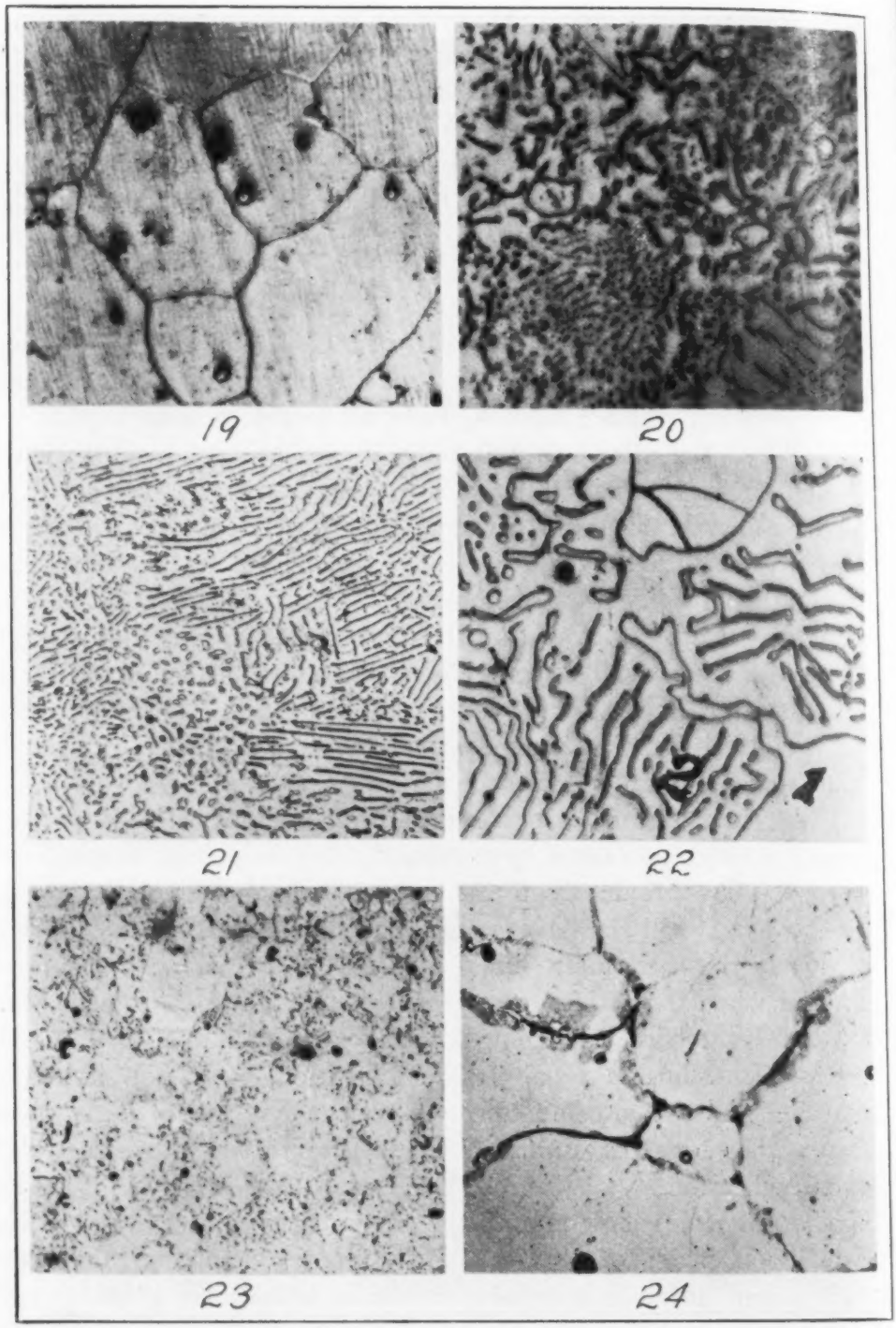
14—Mo 53%, es at 1560° C. Water Quenched 0x. Fig. 16— 775° C. 500x. ach. Cooled to d at 1600° C. —Mo 88%, Fe for 30 Minutes

The pearlite-like appearance of this precipitate suggested at once the likelihood of a eutectoid or eutectic in the molybdenum-rich end of the system. Cooling curves taken on alloys of 70, 80, and 90, per cent molybdenum cooled from 2910 degrees Fahr. (1600 degrees Cent.) show that a slight heat evolution occurs between 2785 and 2730 degrees Fahr. (1530 and 1500 degrees Cent.) in the compositions of 70 and 80 per cent molybednum, but in the 90 per cent molybdenum alloy this is absent. It may be assumed that this heat evolution is the result of the reaction between the iron-rich liquid and the solid molybdenum-rich phases to reform the compound in cooling through the range from 1530 to 1500 degrees Cent., within which range the reaction would be most rapid.

When the alloy contains only 10 per cent of iron there will be no excess compound present at temperatures above 2640 degrees Fahr. (1450 degrees Cent.) none to decompose at 2800 degrees Fahr. (1540 degrees Cent.) and hence no reaction upon cooling from above that temperature. With an iron content of 8 per cent no precipitate occurs until the alloy has cooled to about 2280 degrees Fahr. (1250 degrees Cent.). Below this temperature the compound precipitates in very small particles. The appearance of the precipitate in slowly cooled alloys containing between 10 and 5 per cent of iron is shown in Fig. 23.

An alloy of molybdenum with an iron content below 10 per cent slowly heated to fusion by increasing the amperage through the bars of alloy previously formed at 2730 degrees Fahr. (1500 degrees Cent.), will show large grains of molybdenum-rich solid solution and intergranular films presumably of iron-rich material formed when the solidus temperature had been passed on heating.

An interesting feature of microstructure found in these molybdenum-rich alloys may be worthy of mention in passing. An alloy in which the excess compound has been to any extent decomposed above 2800 degrees Fahr. (1540 degrees Cent.), when water-quenched from say 2910 or 3000 degrees Fahr. (1600 to 1650 degrees Cent.) will show around the edges of the solid solution grains a dark border, Fig. 24. With slightly less rapid cooling this border widens and develops a definite structure which at a high magnification appears to be that of the normal Fe_3Mo_2 precipitate in the slowly cooled molybdenum-rich solid solution. Figs. 25A and 25B. Still slower cooling results in a partial disappearance of the border



Figs. 19 to 24—Photomicrographs of Alloys of Iron and Molybdenum. Fig. 19—Mo 88.5%, Fe 11.5%. Water Quenched from 1530° C. 500x. Fig. 20—Mo 88.5%, Fe 11.5%. Cooled in 5 Minutes from 1530° C. to Room Temperature. 1000x. Fig. 21—Mo 88.5%, Fe 11.5%. Cooled in 30 Minutes from 1650° C. to Room Temperature. 1000x. Fig. 22—Mo 80%, Fe 20%. Cooled from 1600° C. to 1400° C. in 1 Hour and Quenched. (1) Compound Fe_3Mo_2, (2) Mo Rich Solid Solution + Precipitated Compound. 800x. Fig. 23—Mo 94%, Fe 6%. Cooled from 1530° C. to Room Temperature in 1 Hour. 500x. Fig. 24—Mo 85%, Fe 15%. Heated at 1600° C. for 5 Minutes and Water Quenched. 500x.

Fig. 19—Mo
Fe 11.5%.
-Mo 88.5%,
Fig. 22—
nched. (1)
Fig. 23—
Fig. 24—
x.

accompanying a general precipitation throughout the areas of solid solution, fairly well shown in Fig. 26A. The darkened border may also be eliminated by holding the alloy for say 30 minutes at a temperature between 1830 and 2010 degrees Fahr. (1000 and 1100 degrees Cent.) A subsequent quench results in a normal slight and well distributed precipitate. A slow cooling gives the normal heavy precipitate throughout. After either of these treatments the border zones are marked only by a somewhat more massive precipitate than exists generally throughout the solid solution areas.

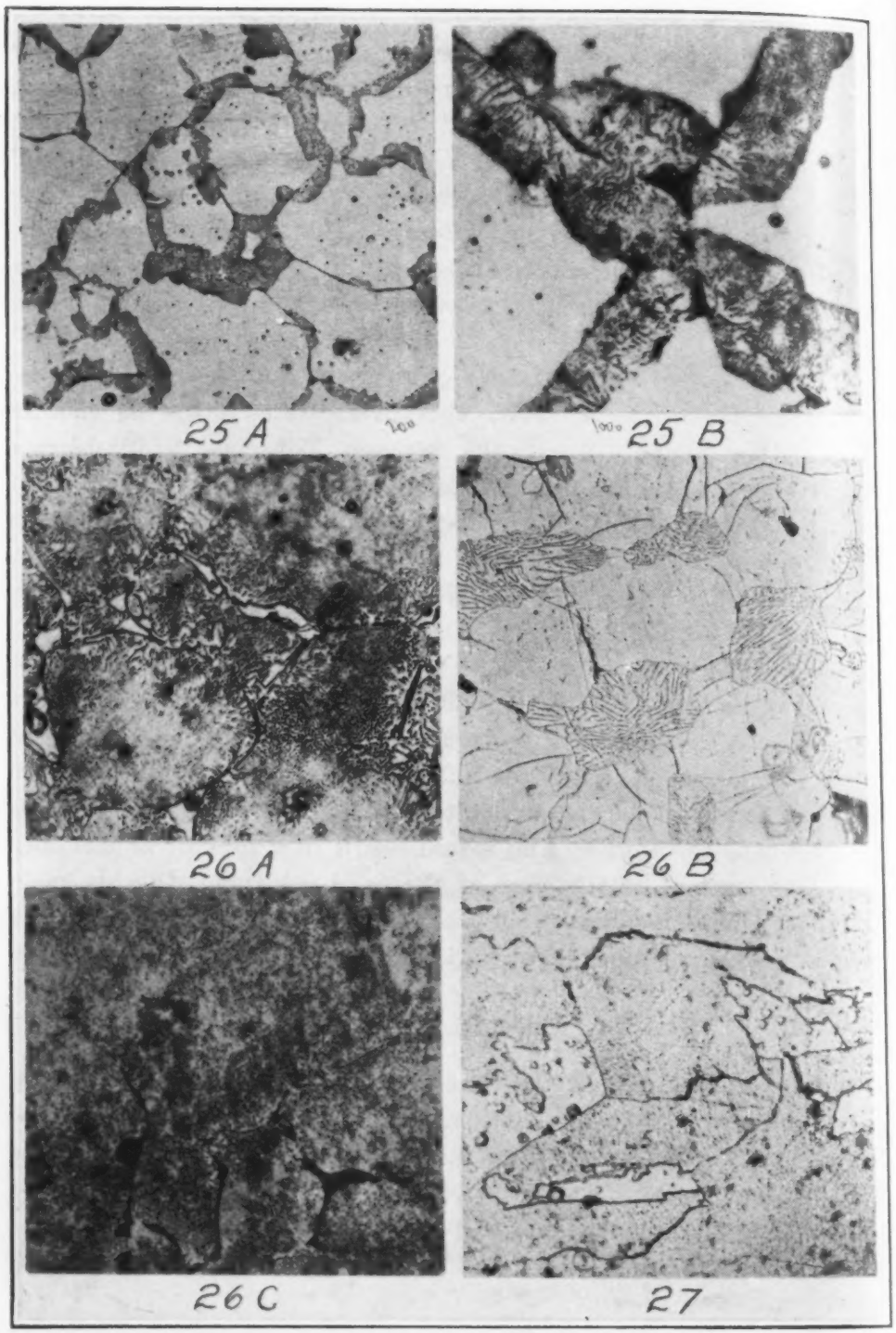
It would seem that the edge of the solid solution area must be extremely rich in iron when this precipitate forms in cooling through the temperature range between 2800 and 2730 degrees Fahr. (1540 and 1500 degrees Cent.) According to the diagram as drawn, the solid solution must be enriched in iron in cooling from 2910 to 2800 degrees Fahr. (1600 to 1540 degrees Cent.) This iron must be supplied by the liquidus material in contact with the solid solution.

Assuming that under conditions of equilibrium the solid solution at 2910 degrees Fahr. (1600 degrees Cent.) contains 10 per cent iron, at 2800 degrees Fahr. (1540 degrees Cent.) 11 per cent iron and again at 2675 degrees Fahr. (1470 degrees Cent.) only 10 per cent iron it seems reasonable to suppose that the arrested diffusion incident to rapid cooling would result in a zone of abnormally high iron content at the edge of the solid solution. In this zone, then, even with rapid cooling precipitation occurs, favored by the abnormally rich iron content and the relatively high temperature.

Critical Points

Alloys containing 3 per cent or less of molybdenum undergo a marked grain refinement when quenched from above 2660 degrees Fahr. (1460 degrees Cent.), Fig. 27, whereas those of higher molybednum content show the large polygonal grains of regular outline whether quenched or slowly cooled from this temperature range. The structure shown in Fig. 2 is typical of the latter class of alloys.

To correlate this phenomenon of grain refinement with the effect of molybdenum on the critical points of pure iron a series of alloys was subjected to a thermal analysis. The specimens, in



Figs. 25A to 27—Photomicrographs of Alloys of Iron and Molybdenum. Fig. 25A—Mo 87.5%, Fe 12.5%. Cooled from 1750° C. to Room Temperature in 30 Seconds. 200x. Fig. 25B—Mo 87.5%, Fe 12.5%. Cooled from 1750° C. to Room Temperature in 30 Seconds. 1000x. Fig. 26A—Mo 85%, Fe 15%. Heated at 1600° C. for 5 Minutes and Cooled to Room Temperature in About 80 Seconds. 500x. Fig. 26B—Mo 70%, Fe 30%. Cooled from 1750° C. to 1450° C. in 1 Hour and Quenched. 200x. Fig. 26C—Mo 88.5%, Fe 11.5%. Cooled from 1600% C. to Room Temperature in 30 Seconds, then Aged at 1000° C. for 1 Hour. 500x. Fig. 27—Mo 2%, Fe 98%. Water Quenched from 1450° C.

the form of pressed blocks about 1″ x 1″ x 3″, each weighing about 200 grams, after drilling for the insertion of the thermocouple, were heated at 2640 degrees Fahr. (1450 degrees Cent.) for 2 hours. The platinum-platinum rhodium couple, inclosed in a thin-walled silica tube was then inserted in the block and the furnace allowed to cool to a black heat. The temperature of the cooling specimen was followed with a galvanometer and potentiometer, readings being taken at intervals of 0.10 millivolts.

In Fig. 28, are plotted the inverse rate cooling curves thus obtained for pure iron and for iron containing molybdenum from 1 to 4 per cent.

Additions of molybdenum to iron lower quite uniformly the temperature of the Ar_4 critical point from 2550 to 2245 degrees

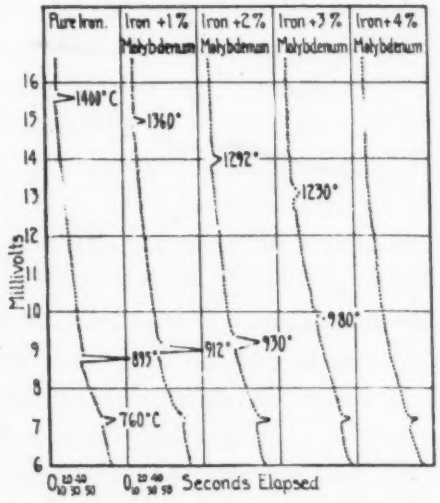


Fig. 28—Inverse Rate Cooling Curves.

Fahr. (1400 to 1230 degrees Cent.) in the alloy containing 3 per cent by weight of molybdenum. The Ar_3 is raised from 1640 to 1795 degrees Fahr. (895 to 980 degrees Cent.) by 3 per cent of molybdenum. The heat evolutions become less and less pronounced and in the 4 per cent alloy are not detectable with the equipment used in obtaining these data. No change was observed in the position of the Ar_2 point, and it persists in a 20 per cent molybdenum alloy, though with diminished intensity.

In the equilibrium diagram, Fig. 1, the line MHN is drawn through the positions of the Ar_4 and Ar_3 points as indicated during cooling. The broken portion of the line represents the location of these points and their probable merging in the composition

range where they are too weak for detection.

Investigators have determined by means of the X-ray the atomic structure of iron in its three allotropic forms. Below 1650 degrees Fahr. (900 degrees Cent.) alpha or body-centered cubic iron is the stable form. Between 1650 and 2550 degrees Fahr. (900 and 1400 degrees Cent.) iron exists in the gamma state, having a face-centered cubic lattice. Above 2550 degrees Fahr. (1400 degrees Cent.) a body-centered cubic form is again the stable phase and this phase is known as delta iron.

The thermal point Ar_3 marks the change from gamma to alpha, and the point Ar_4 from delta to gamma iron.

It would appear from the foregoing that the addition of molybdenum to iron tends to prevent the change in form from alpha to gamma, or from delta to gamma in heating through Ar_3 or cooling through Ar_4 respectively. In other words additions of molybdenum to iron progressively restrict the range in which gamma iron is stable, until with a molybdenum content of 4 or 4½ per cent the body-centered form prevails exclusively at any temperature below the solidus.

Certain other elements have been found to affect the gamma iron range in a manner similar to molybdenum.

In the iron-silicon system, Oberhofer[1] initially reported that with more than 5 per cent silicon no face-centered iron was present. As a result of a more recent investigation of this system by Giani, Reinecken and Wever[2], this figure has been lowered to about 1.8 per cent silicon. The last named investigators report that 2 per cent tin marks the end of the gamma iron range in the iron-tin system.

From the cooling curves of low carbon vanadium steels published by Maurer[3], it would seem that the changes delta to gamma and gamma to alpha are absent when the vanadium content exceeds about 2.5 per cent. According to Bain[4] about 14 per cent chromium is required to eliminate the gamma range in alloys of iron and chromium.

The present writer has reported that in iron-tungsten alloys

[1]Zur Kenntnis der Eisen-Silizium-Legierungen; P. Oberhoffer; *Stahl und Eisen*, August, 1924.

[2]Zur Allotropie des Eisens; Franz Wever, *Stahl und Eisen*, July, 1925.

[3]Zur Kenntnis der Vanadinstähle; E. Maurer, *Stahl und Eisen*, September, 1925.

[4]The Nature of the Alloys of Iron and Chromium; E. C. Bain, TRANSACTIONS, American Society for Steel Treating, January, 1926.

containing more than 6 per cent tungsten only the body-centered cubic lattice is present at any temperature below the solidus.[5]

The grain refinement brought about by quenching from above 2550 degrees Fahr. (1400 degrees Cent.) alloys containing up to 3½ per cent molybdenum results in a considerable increase in hardness. This hardening reaches a maximum with a molybdenum content of about 3 per cent. Fig. 29.

Hardness Measurements

The alloys of the iron-molybdenum system display a continuous rise in Brinell and Rockwell hardness as the molybdenum content is increased up to about 40 per cent. Compositions in the

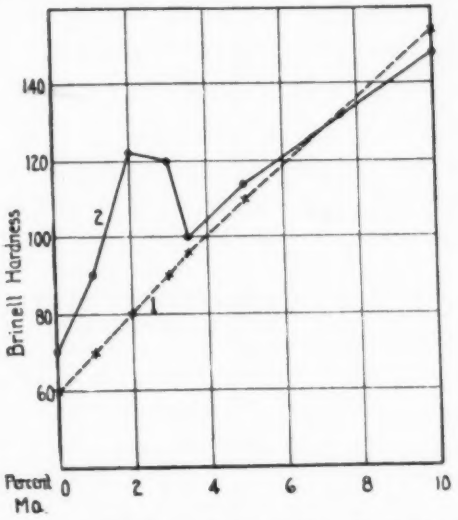


Fig. 29—Curves Showing Brinell Hardness of Iron-Molybdenum Alloys. (1) Cooled from 1475° C. to 500° C. in 1 Hour. (2) Water Quenched from 1475° C.

range between 40 and 85 per cent molybdenum, while sufficiently hard to scratch glass are somewhat porous and brittle and hence are unsuitable for Brinell or Rockwell hardness determination.

Iron is very effective in raising the hardness of molybdenum. As little as 3 per cent of iron by weight when dissolved in molybdenum increases the Brinell hardness number from 125 to 281, and the Rockwell hardness from C 5 to C 37, while the alloy containing 15½ per cent iron as quenched from 2775 degrees Fahr. (1525 degrees Cent.) has a Brinell of 490 and Rockwell of C 58.

The hardness considered thus far is that shown by the alloys

[5]The Iron Tungsten System; W. P. Sykes, *Transactions*, American Institute of Mining and Metallurgical Engineers, February, 1926.

as either quenched from a temperature just under the liquidus or furnace cooled in about 1 hour from such a temperature. Except in the range between 0 and 4 per cent molybdenum slow cooling results in a somewhat higher hardness than quenching, due to the abundant precipitate of hard Fe_3Mo_2.

In Table I are listed the hardness numbers of such of those alloys in the system which could be successfully subjected to the Rockwell and Brinell method of test.

The Rockwell hardness of figures are plotted against composition in Fig. 30.

Hardness Increase Produced by Aging

Alloys of this system made up wholly or in part of the solid solutions of molybdenum in iron or iron in molybdenum can be heat treated in such a way as to change very materially certain of their physical properties.

If an alloy of 20 per cent molybednum in iron be rapidly cooled from 2595 degrees Fahr. (1425 degrees Cent.) to room

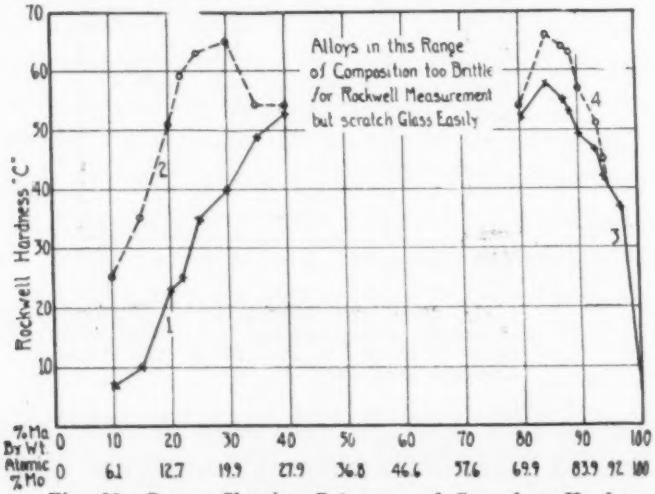


Fig. 30—Curves Showing Primary and Secondary Hardness (Rockwell "C") of Iron-Molybdenum Alloys. Hardness (1) As Quenched from 1425° C. (2) and Aged 20 Hours at 625° C. (3) As Quenched from 1525° C. (4) and Aged 20 Hours at 775° C.

temperature it will consist entirely of a solid solution of molybdenum in iron supersaturated with respect to molybdenum, since under equilibrium conditions only about 6 per cent of molybdenum will be held in solution at room temperature. If now this alloy as quenched, be heated or aged for successive periods of time at some temperature between 1110 and 1290 degrees Fahr. (600 and 700 de-

grees Cent.) its hardness will gradually increase, attain a maximum and at last with prolonged heating slowly decrease.

In the iron-rich alloys the secondary hardness begins to develop at an aging as low as 930 degrees Fahr. (500 degrees Cent.), though very slowly. At 1020 degrees Fahr. (550 degrees Cent.) the hardness approaches its maximum only after aging for 250

Table I

Brinell and Rockwell Hardness of Iron-Molybdenum Alloys

Composition	As Quenched 1425°C.		After Aging 20 hrs. at 625°C.	
	Brinell	Rockwell "C"	Brinell	Rockwell "C"
Pure Iron	60			
Iron+3% Mo.	100			
5% Mo.	110			
10% Mo.	146	7	218	25
15% Mo.	173	10	240	35
20% Mo.	200	23	437	51
22% Mo.	225	26	530	59
25% Mo.	233	35	545	63
30% Mo.	272	40	620	65
35% Mo.	Too brittle	49	Too brittle	54
40% Mo.	Too brittle	53	Too brittle	54
	As Quenched 1525°C.		After Aging 20 hrs. at 775°C.	
Pure Mo.	125	5		
Mo+1½% Iron ..	235	23		
3 % Iron ..	281	37		
7 % Iron ..	349	47	440	51
10 % Iron ..	375	49	520	57
11½% Iron ..	412	53	550	63
12½% Iron ..	464	55	585	64
15½% Iron ..	490	58	640	66
20 % Iron ..	cracks	52	cracks	54

hours. At 1155 degrees Fahr. (625 degrees Cent.) the maximum hardness is attained in about 10 hours, and a slight decrease in hardness is noticeable after 30 or 40 hours aging. As the temperature of aging is raised the hardness increase occurs more rapidly, but the maximum value is always less than that developed by aging at a lower temperature, and softening progresses likewise at a more rapid rate.

Table II and Figs. 31 and 32 show the relations between the temperature and times of aging and the secondary hardness developed in alloys of 20 and 25 per cent molybdenum in iron.

Alloys in the molybdenum-rich end of the series likewise develop a secondary hardness. To attain their greatest hardness these alloys must be drastically quenched from about 2775 degrees Fahr. (1525 degrees Cent.) and aged at a temperature about 100

degrees Cent. higher than that used for the iron-rich alloys. The increase in hardness brought about by aging is less in the latter group of alloys than in the iron-rich series, though the highest hard-

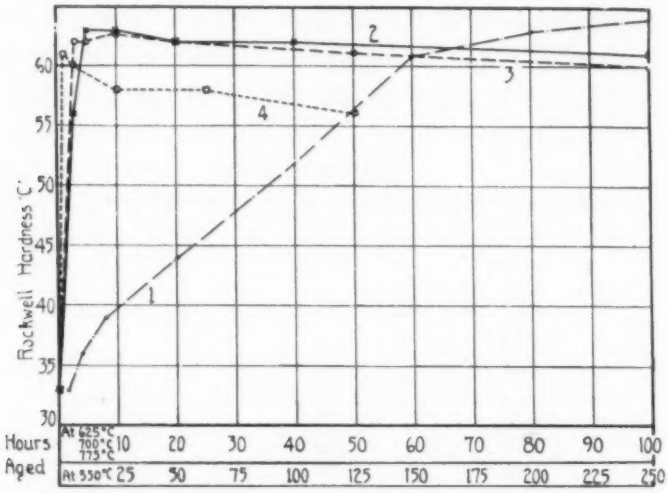


Fig. 31—Curves Showing Rockwell Hardness "C" Tests. Iron 75%, Molybdenum 25%. Quenched from 1425° C. and Aged at (1)—550° C. (2)—625° C. (3)—700° C. (4)—775° C.

ness developed in either group is between C 66 and C 67, which is attained by the alloy of 15½ per cent iron in molybdenum.

Both primary and secondary hardness of alloys in both ends of the system are plotted in Fig. 30 primarily to show the relation between composition and hardness.

Microstructure as Affected by Aging

Certain interesting features in the microstructure of the alloys develop during the aging operation. As noted before, the structure of a 22 per cent molybdenum alloy as quenched consists of the coarse-grained solid solution shown in Fig. 2. Prolonged etching in the nitric acid and alcohol reagent reveals only the grain boundaries.

After 5 hours heating at 1020 degrees Fahr. (550 degrees Cent.) the hardness has increased from C 25 to C 30. After this treatment, etching develops within the solid solution darkened lines, apparently of two types, as shown in Fig. 33, one type comprises fine lines of a somewhat wavy appearance, suggestive of strain lines. The lines of the second type are long, straight and well marked and resemble twinning lines. This phenomenon may

be the result of strains set up in the metal in the previous quenching operation, or perhaps in polishing.

Further aging of the alloy results in a microstructure which etches rapidly and shows a section uniformly darkened, and

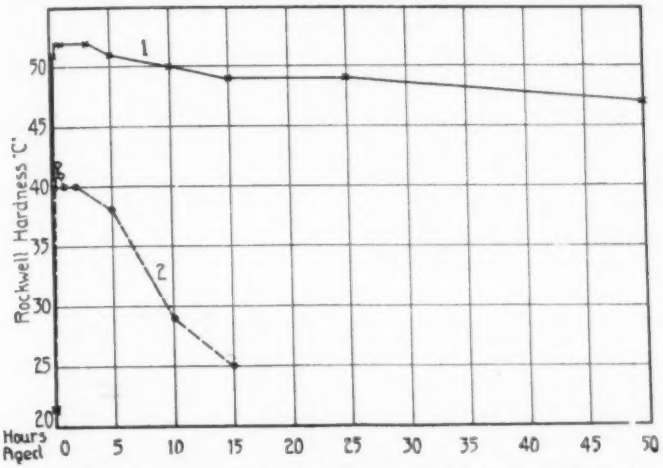


Fig. 32—Curves Showing Rockwell Hardness "C" Tests. Iron 80%, Molybdenum 20%. Quenched from 1425° C. and Aged at (1)—775° C. (2)—950° C.

marked only by the grain boundaries which sometimes inclose narrow bands of the unetched compound presumably left undissolved at the temperature of quench. Fig. 34 shows such a section, and is representative of the structure found in the alloy in its condition of greatest hardness.

By prolonging the time at 1155 degrees Fahr. (625 degrees Cent.) or by aging at a higher temperature until the hardness has

Table II

Iron + 25% Molybdenum—Water Quenched 1425°C.
Temperature of Aging Versus Hardness
Time of Aging Versus Hardness (Rockwell "C")

Hours At	550°C			625°C	700°C	775°C
½	C 33		238	C 37	C 40	C 61
1	C 33		238	40	C 45	61
3	C 33	Brinell	240	C 56	C 60	60
5	C 36	Brinell	248	63	62	60
10	C 36	Brinell	248	63	63	58
20	C 39	Brinell	290	62	62	58
30	C 41	Brinell	302	62		56
50	C 44	Brinell	316	62	61	56
100	C 52	Brinell	465	61	60	..
150	C 61	Brinell	508	..	..	..
200	C 63	Brinell	545	..	..	..
250	C 64	Brinell	580	..	..	..

Hardness as Water Quenched from 1425°C C 33
Hardness as Cooled in 1 hour from 1425°C C 36

decreased somewhat below the maximum a well developed precipitate appears in the etched section.

In Fig. 35 is shown the structure of an alloy containing 22 per cent molybdenum which has been aged at 1560 degrees Fahr. (850 degrees Cent.) for 20 hours. The maximum hardness de-

Table III

Molybdenum 15.5% Iron-Water Quenched from 1525°C
Time of Aging Versus Hardness (Rockwell "C")
Temperature of Aging Versus Hardness

Hours At	700°C	775°C	900°C
½	..	..	C 59
1	C 56	C 60	60
3	58	62	60
5	58	63	60
10	60	65	58
20	62	65	55
30	63	65	..
50	65	65	..
75	66	..	..
100	67	..	..

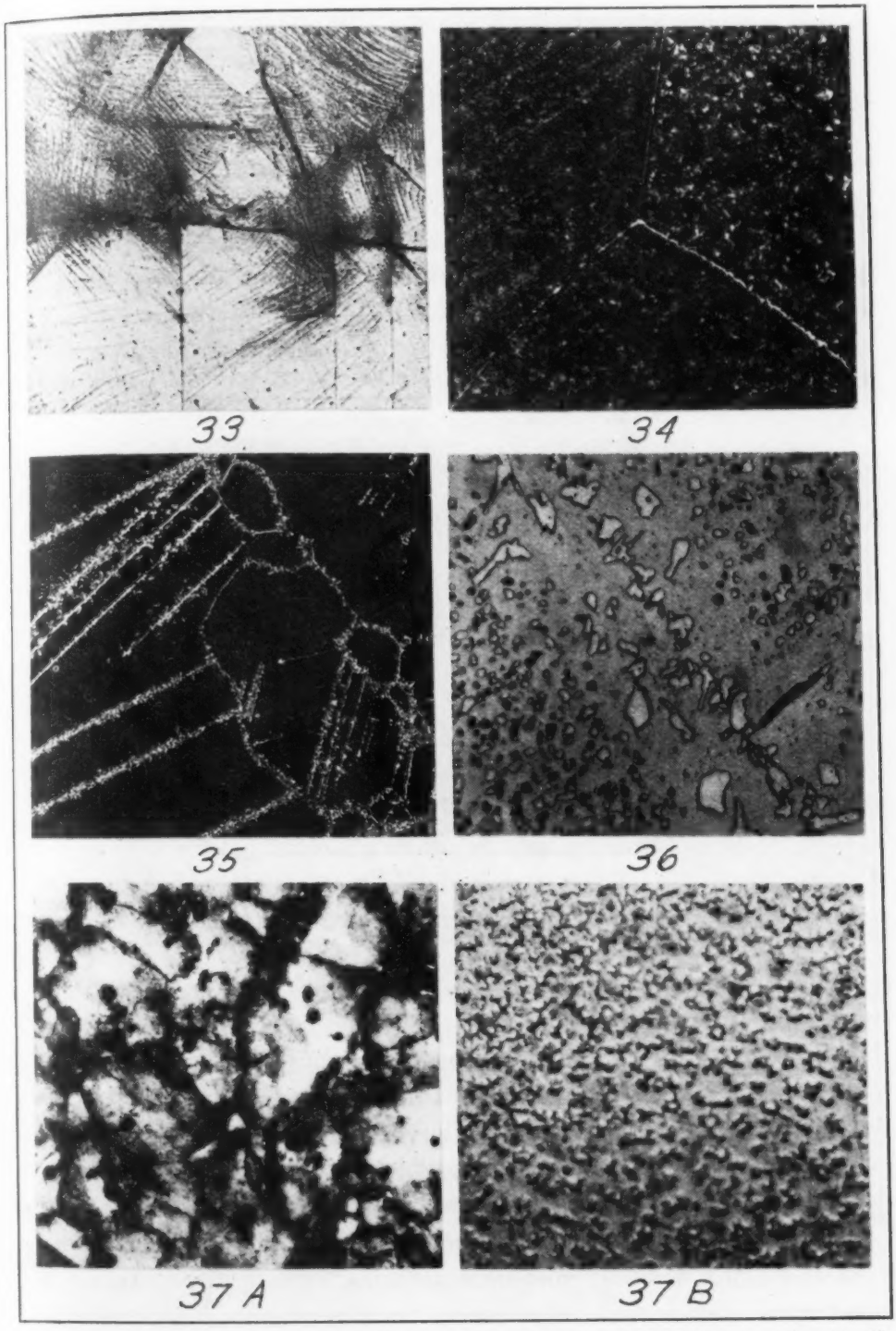
Hardness as Water Quenched from 1525°C C 56

veloped at this aging temperature was C 50 after aging ½ hour. After 20 hours the hardness had dropped to C 39 and the precipitate is concentrated at the grain boundaries and along the lines of the second type previously noted in the early stages of aging and shown in Fig. 33.

If an alloy in the quenched condition be deformed locally, as with the Rockwell diamond cone, and then aged for a short time at about 1110 degrees Fahr. (600 degrees Cent.) the solid solution immediately surrounding the impression becomes dark upon etching while the remainder of the field is not discolored. This would indicate that deformation favors the precipitation from solid solution.

By aging a quenched alloy at 1830 degrees Fahr. (1000 degrees Cent.) for some hours the precipitate appears as particles easily resolved at a magnification of 500 diameters, Fig. 36. This alloy of 20 per cent molybdenum in the quenched condition showed a Brinell hardness of 200. During the aging at 1830 degrees Fahr. (1000 degrees Cent.) the hardness rapidly passes through its maximum value and after three hours the Brinell number is 248.

The photomicrographs in Figs. 37A and 37B illustrate the effects of aging in the molybdenum-rich alloys. In their hardest



Figs. 33 to 37B—Photomicrographs of Alloys of Iron and Molybdenum. Fig. 33—Mo 22%, Fe 78%. Quenched from 1425° C. Aged 5 Hours at 550° C. 200x. Fig. 34—Mo 22%, Fe 78%. Quenched from 1425° C. Aged 60 Hours at 600° C. 1000x. Fig. 35—Mo 22%, Fe 78%. Quenched from 1425° C. Aged 20 Hours at 850° C. 100x. Fig. 36—Mo 22%, Fe 78%. Quenched from 1425° C. Aged 3 Hours at 1000° C. 500x. Fig. 37A—Mo 87.5%, Fe 12.5%. Quenched from 1530° C. Aged 15 Hours at 775° C. Dark Pits Mark Positions of Excess Fe_3Mo_2 Removed by Heavy Etching Necessary to Develop Shaded Areas in Molybdenum Rich Solid Solution. 500x. Fig. 37B—Mo 87.5%, Fe 12.5%. Quenched from 1530° C. Aged 50 Hours at 775° C. 1000x.

state, a heavy etch produces a mottled appearance in the areas of molybdenum-rich solid solution. Over-aging results in the growth of the precipitated particles and the granular appearance as in Fig. 37B. The alloy in the latter case has passed through its stage of greatest hardness C 64 and in the condition shown Rockwells C 62.

The molybdenum-rich alloys in the quenched condition emit a "crackling" sound when deformed under the Rockwell diamond.

Fig. 37C illustrates the results of such deformation. This photomicrograph was taken near the diamond impression which

Fig. 37C—Photomicrograph of Alloy of Iron and Molybdenum. Mo 87.5%, Fe 12.5%. Quenched from 1530° C. Rockwell Diamond Impression Made on Polished Surface After Quench. Light Etch. 200x.

was made upon a polished section of the quenched alloy, etched lightly before the impression was made, but not afterwards.

A few intergranular cracks radiate from the impression. For some distance around the impression are seen within any one grain, one or two sets of parallel lines which correspond in appearance with the description of Neumann bands given by Howe[6].

Such an alloy when slowly cooled and in which the precipitation of Fe_3Mo_2 is fairly complete deforms without the "crackling" mentioned above and after such treatment the intercrystalline cracks rarely appear nor do the Neumann bands.

The latter when present in any case can be eliminated only

[6]The Metallography of Steel and Cast Iron, p. 415.

by heating the alloy for some hours at a temperature of 2190 or 2370 degrees Fahr. (1200 or 1300 degrees Cent.)

Volume Change during Aging

Blocks measuring approximately 1″ x 1″ x ⅝″ were prepared from an alloy of 22 per cent molybdenum, 78 per iron. After water quenching from 2595 degrees Fahr. (1425 degrees Cent.) two opposite faces on each were ground and measurements made with a precision micrometer to 0.0001 inch between the ground faces. The blocks were then aged at 1200 degrees Fahr. (650 degrees Cent.) in a hydrogen atmosphere for periods of time ranging from 30 minutes to 50 hours.

Measurements made after aging showed a linear shrinkage increasing with time of aging to a maximum value of 0.0045 inch in a length of 0.9875 inch. This maximum of 0.455 per cent shrinkage was found in the block aged for 5 hours at which time the hardness was nearing its highest value. A slight increase in volume appears to result from extended aging, though even after 50 hours the total shrinkage is still 0.004 inch.

The linear shrinkages and corresponding hardness measurements are plotted in Fig. 38.

Effect of Carbon on the Iron-Rich Molybdenum Alloys

A preliminary investigation of the iron-carbon-molybdenum system indicates that in the iron-rich molybdenum alloys carbon in excess of about 0.1 per cent materially alters the conditions governing the development of hardness in these alloys.

Generally speaking, with a fixed percentage of molybdenum an increase in carbon content results in higher hardness as quenched, but lower hardness after aging.

An example of this effect is offered by a comparison of the carbon-free alloy of molybdenum 22 per cent iron 78 per cent with the same alloys containing 0.31 per cent carbon.

	Rockwell Hardness	
	As Quenched from 1300°C	After Aging 12 hrs. 650°C
Carbon Free Alloy	C 25	C 58
Alloy with .31% C	C 32	C 50

Practical Considerations

One alloy of the system has proved to be of decided value as a material for swaging dies used in the process of working tungsten at a high temperature. In this operation the swaging die hammers a tungsten bar which is at times at a temperature as high as 2550 or 2730 degrees Fahr. This alloy of 22 per cent molybdenum,

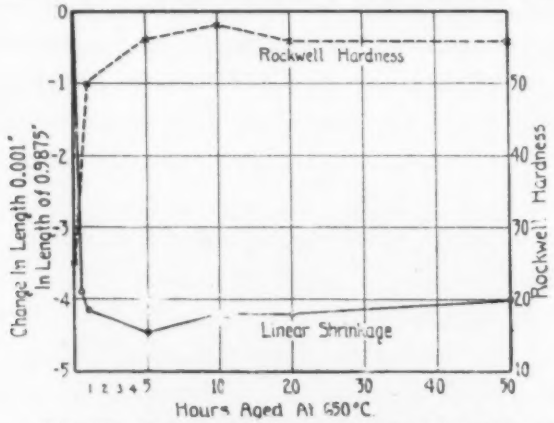


Fig. 38—Curves Showing Change in Dimension and Hardness of Alloy Mo 22%, Fe 78%. Quenched from 1400° C. and Aged at 650° C.

78 per cent iron has replaced high speed steel formerly used for dies in the above operation and has a life which will average from 30 to 50 times that obtained from the most satisfactory high speed steel. This advantage is gained by virtue of the ability of the iron-molybdenum alloy to retain its hardness at elevated temperatures. Hardness measurements on specimens of the aged alloy and of hardened high speed steel heated together at 1110 degrees Fahr. (600 degrees Cent.) over a period of 50 hours are shown in Fig. 39 and illustrate very clearly the superiority of the alloy in high temperature hardness.

The alloy of 22 per cent molybdenum, 78 per cent iron as will be noted from the equilibrium diagram, contains an amount of molybdenum slightly less than that which can be dissolved in iron below the eutectic temperature. In preparing this alloy, blocks of the pressed powders measuring 3″ x 1¾″ x 1″ after heating in a reducing atmosphere at about 2550 degrees Fahr. (1400 degrees Cent.) for 1 hour to form the solid solution are then cooled to room temperature in about 1 hour.

In this condition the alloy can be machined almost as readily as annealed high speed steel. The dies machined from the alloy

measuring 1¼" x 1" x ¾" are again heated at 2550 degrees Fahr. (1400 degrees Cent.) for 10 minutes to dissolve the molybdenum previously precipitated by the slow cooling and quenched in water

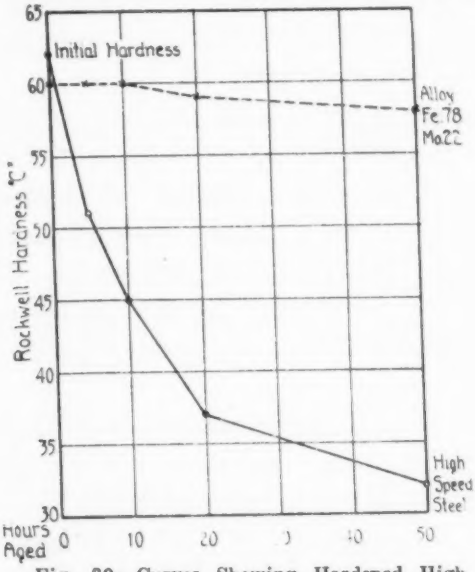


Fig. 39—Curves Showing Hardened High Speed Steel and Iron-Molybdenum Alloy Heated at 600° C.

until almost dark then withdrawn and cooled in air. This interrupted quench is necessary to prevent occasional cracking in pieces as large as those mentioned. Smaller pieces of this composition can be completely cooled in water without cracking.

Following the quench the dies are heated for 12 hours at 1155 degrees Fahr. (625 degrees Cent.) in an electric muffle furnace

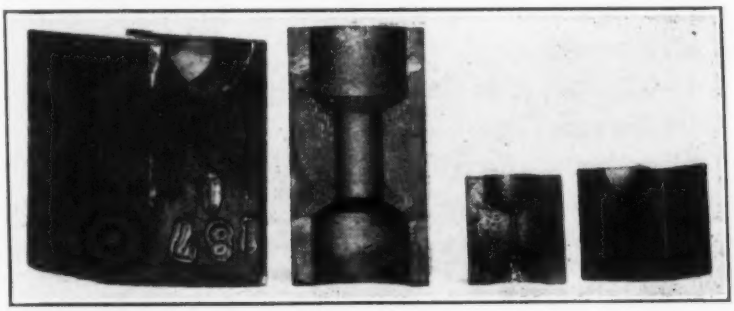


Fig. 40—Photograph of Swaging Dies Made from Alloy of Mo 22%, Fe 78%, About 8/10 Actual Size.

equipped with an automatic temperature control. Fig. 40 is a photograph of two pairs of such dies.

Iron-rich alloys with molybdenum content much above 22 per

cent tend to crack upon quenching completely in water. They also become less resistant to shock with increasing molybdenum content.

Since no grain refinement occurs in these alloys during cooling from elevated temperatures the structure is always extremely coarse. Largely due to this coarseness of grain the alloys are rather brittle at ordinary temperatures.

Iron containing as high as 22 per cent of molybdenum can be worked at temperatures around 2190 degrees Fahr. (1200 degrees Cent.) by rolling, forging or swaging. Such working results in a certain amount of grain refinement. This advantage is largely lost, however, when the worked alloy is reheated to 2550 degrees Fahr. (1400 degrees Cent.) before the quench, which operation is necessary to the development of the secondary hardness by subsequent aging.

The alloys in the molybdenum-rich end of the series containing from 10 to 16 per cent iron even in their softest state can be machined with steel tools only with difficulty.

The alloys of molybdenum with 13 to 16 per cent iron in their hardest state have been used with excellent results as dies for drawing tungsten and molybdenum wire at temperatures between 1110 and 1470 degrees Fahr. (600 and 800 degrees Cent.)

Tensile Properties

Tensile tests were made on 0.030 inch wires of an alloy of iron 12 per cent molybdenum as slowly cooled, as quenched, and as quenched and subsequently aged at 1155 degrees Fahr. (625 degrees Cent.). The resulting data listed in Table IV, contain several features of interest.

It is to be noted that the wires as quenched from 2370 degrees Fahr. (1300 degrees Cent.) and broken in tension assume the shape of a perfect wedge at the point of rupture. As this would indicate, the cross section of the wire is in places made up of a single grain of solid solution; rupture occurs here within such a grain and the accompanying reduction is practically 100 per cent in one direction determined by the position of the planes of easy slip.

This type of reduction in several pure metals has been previously described, and the tensile strength and elongation accompanying such a fracture in pure iron is listed in the table for purposes of comparison. The 12 per cent molybdenum in solid solution has

Table IV

Description		Tensile Strength Lbs./Sq. In.	Per Cent Elongation in 2 In.	Remarks All Wires .030″ Diameter
Fe 12% Mo. Quenched from 1300° C. and aged at 625° C.				
30 Min.	A	66,000	6.3	A. Semi wedge reduction.
	B	60,000	4.7	B. Full wedge reduction.
	Avg.	63,000	5.5	
1 Hour	A	61,500	4.7	A. Smooth fracture at slight angle to axis of wire—no measurable reduction.
	B	66,500	6.3	
	Avg.	64,000	5.5	B. Semi wedge reduction.
5 Hours	A	85,000	3.1	A. Semi wedge reduction.
	B	76,500	6.2	B. Semi wedge reduction.
	Avg.	80,700	4.7	
10 Hours	A	150,000	1.5	A. No measurable reduction—both fractures smooth, at angle to axis of wire.
	B	127,000	1.5	B.
	Avg.	138,500	1.5	
20 Hours	A	153,000	0.7	A. Fracture rough } No measurable reduction.
	B	142,000	0.7	B. Fracture smooth }
	Avg.	147,000	0.7	
50 Hours	A	123,000	0.7	A. Fracture smooth } No measurable reduction.
	B	150,000	0.7	B. Fracture rough }
	Avg.	136,500	0.7	
Pure Iron Furnace Cooled from 1400° C.		24,000	19.5	Fracture occurs within single grain—full wedge reduction.
Fe 12% Mo Water Quenched from 1300° C.				
	A	56,500	6.2	A. Full wedge reduction.
	B	60,000	4.7	B. Full wedge reduction.
	Avg.	58,200	5.5	
Fe 12% Mo Cooled from 1300° C. to Room Temp. in 30 Min.				
	A	91,800	5.5	} Reduction about 5%.
	B	93,300	7.7	} Rough fractures.
	Avg.	92,500	6.6	

increased the tensile strength of the iron by about 140 per cent as measured on a single crystal. The ductility as indicated by the elongation figures is very much lower in the case of the solid solution.

The relatively massive particles of Fe_3Mo_2 precipitated in the alloy by slow cooling result in a much higher tensile strength, and decidedly alter the character of the fracture. The reduction of area in such a wire is about 5 per cent and the surface of the fracture is coarse and irregular throughout the section.

By aging the quenched alloy at 1155 degrees Fahr. (625 degrees Cent.) the tensile strength is increased to about 150,000 pounds per square inch, from 58,000 pounds per square inch, that of the alloy before aging. Due to the large grain size of the test specimens the tensile strength values are very erratic as might be expected from the description of the fractures following each test. A new type of fracture sometimes occurs in the wires aged for one hour or longer. It is best described as a smooth bright surface extending over the entire cross section and making a slight angle with the axis of the wire.

The wedge-shaped fracture persists imperfectly in the wires aged 5 hours, and breaking at 80,000 pounds per square inch. It does not occur after longer aging times.

Increases in hardness and tensile strength of alloys brought about by aging have been previously reported for certain other alloys. Merica, Waltenberg, and Scott[7] described this effect in duralumin, and proposed their theory of age hardening to explain it. Age hardening in the lead-antimony system has been reported by Dean, Zickrick and Nix[8], in the iron-tungsten system by the present author[5], and in certain magnesium base alloys by Jeffries and Archer[9].

Summary

The system iron-molybdenum comprises:

(a) Solid solution of molybdenum in iron, 24 per cent of molybdenum being soluble at 2625 degrees Fahr. (1440 degrees Cent. and 6 per cent at room temperature.

(b) A eutectic at 36 per cent molybdenum being a conglomerate of the compound Fe_3Mo_2 and the solid solution of molybdenum in iron.

(c) The compound (Fe_3Mo_2) iron molybdide at the composition 53.4 per cent molybdenum.

(d) Beyond this composition there may be present if not heated above 2800 degrees Fahr. (1540 degrees Cent.), the compound plus molybdenum-rich solid solution. If heated above 1540 degrees Cent. the Fe_3Mo_2 decomposes into iron-rich and molybdenum-rich phases.

[7]Merica, Waltenburg and Scott; Heat Treatment and Constitution of Duralumin. *Transactions*, American Institute of Mining and Metallurgical Engineers, 1920.

[8]The Lead-Antimony System and Hardening of Lead Alloys; R. S. Dean, Lyall Zickrick, and F. C. Nix. *Transactions*, American Institute of Mining and Metallurgical Engineers, 1926.

[9]U. S. Patent No. 1,592,302.

(e) Molybdenum dissolving 11 per cent of iron at 2790 degrees Fahr. (1535 degrees Cent.) and at room temperature about 5 per cent of iron.

The critical point Ar_4 is lowered from 2550 to 2245 degrees Fahr., (1400 to 1230 degrees Cent.) and the point Ar_3 is raised from 1635 to 1795 degrees Fahr. (890 to 980 degrees Cent.) by the addition of 3 per cent of molybdenum to iron.

The Brinell and Rockwell hardness of iron increases continuously with the addition of molybdenum up to about 40 per cent by weight. The hardness of molybdenum is increased at a more rapid rate by the addition of iron up to about 15 per cent.

The Rockwell hardness of some of the alloys, water-quenched from just below the solidus, is increased by as much as 250 per cent by aging at temperatures between 1110 and 1200 degrees Fahr. (600 and 700 degrees Cent.)

In aging at certain given temperatures the hardness reaches a maximum and then decreases as aging is prolonged.

The higher the temperature of aging above a certain minimum temperature, the more rapidly the hardness increases, but the lower is the maximum hardness attained.

The tensile strength like the hardness increases with aging; a decrease in ductility accompanies the increase in tensile strength. Development of secondary hardness in these alloys is accompanied by the precipitation of the compound Fe_3Mo_2. The particle size of the precipitate remains sub-microscopic until the hardness has passed through its maximum value and has fallen off considerably.

A shrinkage in volume occurs during the aging process and, in general, its maximum is coincident with that of the maximum hardness developed by aging.

Acknowledgements

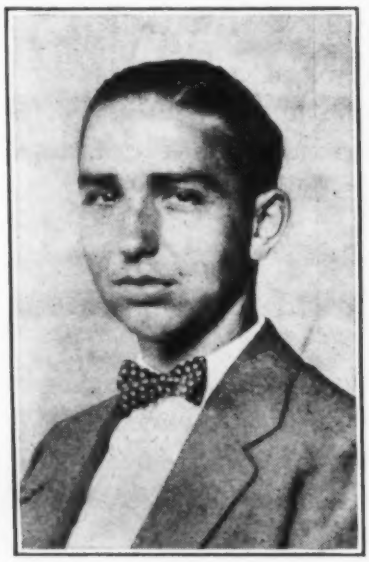
P. P. Tarasov, metallurgist at the Cleveland Wire Works, rendered valuable assistance in obtaining the cooling curves included in this paper.

The precision measurements of the alloy blocks, as quenched and aged, were made by T. L. Robinson, metallurgist, The McGill Metal Company, Valparaiso, Ind.

I wish to thank Dr. Jeffries for his helpful interest in this investigation.

The Author

W. P. Sykes was born in 1893 and received his early education in the Cleveland Public Schools after which he attended Case School of Applied Science, graduating in 1916, receiving the degree of Bachelor of Science in Metallurgy. In 1920, he received the degree of Metallurgical Engineer in recognition of the work he had done in the field and upon which he submitted the thesis entitled, "Effect of Temperature, Deformation, and Grain Size on the Tensile Properties of Metals." After graduating from Case School he became affiliated with the Cleveland Wire Works, Incandescent Lamp Department of the General Electric Company, Cleveland, Ohio. His early work was concerned principally with the metallurgy of tungsten and molybdenum and later with high melting point alloys. Mr. Sykes' work is concerned chiefly with the development of metals and alloys used in the process of incandescent lamp making.



W. P. SYKES

DISCUSSION

I. C. Matthews: I would like to ask Mr. Sykes which percentage of molybdenum gives the greatest ductility when drawn into wire?

W. P. Sykes: That is a rather difficult question to answer at the present time. The ductility falls very rapidly as the molybdenum content is increased. I used in those pieces for tensile test no higher than 12 per cent molybdenum, because at that time I did not have the opportunity to work with a higher percentage. I tried 15 and 20 per cent, but after I began to draw them, even at quite elevated temperatures, they hardened so rapidly during the cooling between dies that they were pretty hard to work with. But I think it could be drawn with proper care even as high as, say, 15 or 18 per cent of molybdenum.

E. C. Bain: I should like, first of all, to express appreciation of and admiration for this paper. I know that I but voice the reactions of all of us who study the metals when I express admiration for this outstanding example of craftsmanship in metallographic research. The broad understanding of metallurgical principles exhibited in this investigation guarantees that the

iron-molybdenum constitution diagram as constructed by Sykes will not suffer alteration by succeeding investigators as has often happened to pioneer diagrams in the past.

It may not be out of place at this time to suggest a matter for thought to workers in ferrous alloys. In connection with the so-called "Delta" iron, we have, all of us, used the word because it was applied long ago to nearly pure iron as it existed at high temperatures above the stable range for gamma iron. In my own studies of iron-chromium solid solutions I conformed to the earlier nomenclature, but when this name was originally chosen much less of its nature was known.

In past times we have learned much about the effect of those elements, more soluble in gamma iron than in alpha iron, which stabilize and widen the range of austenite. Still more recently we divide alloying elements into two classes—those acting as mentioned (carbon, nickel, manganese and probably cobalt) and a less familiar group (chromium, tungsten, molybdenum, silicon, tantalum and probably tin) which are more soluble in the alpha modification of iron, and which limit and restrict the range of austenite stability. In the presence of these elements in solid solution we know that ferrite may be stable at all temperatures up to the melting point. In the case of chromium, at least, when the alloy is not rich enough to eliminate entirely the gamma state, we can quench the alloy from temperatures near the melting point and secure unchanged at room temperatures the high temperature form. It is simply ferrite–alpha iron solid solution. As correctly plotted, then, on a constitution diagram, one can trace a *single phase* all the way from pure iron ferrite to pure delta iron. Delta iron and its solid solutions then are entirely identical with alpha iron and ferrite.

With these proofs (and there are others) of the identity of the two crystalline entities, may we not consider restricting or perhaps even dropping the use of the word Delta iron? If we wish to discriminate between the manner of formation of the two particular ferrites—one being formed by heating austenite to a temperature above its existence and quenching—the other formed by cooling austenite at a proper rate for its complete recrystallization, then Alpha iron and Delta iron take on significance. In any case the point is one for leisurely consideration and will ultimately be decided upon the basis of expediency for purposes of accurate and lucid nomenclature, and for simplicity of viewpoint; but the beginner may be inclined to think of Delta iron as some distinct allotropic modification whereas at present the preponderance of evidence is definitely opposed to this conception.

DR. HARDER: I would like also to express appreciation of this paper.

There is one point I would like to ask about and that is the mechanism of the shrinking on aging at the various temperatures, and I would like to inquire if the change in the unite parameter and the space lattice has been considered as a possible mechanism in that shrinkage. On certain work that we have done on X-ray analysis we have found a certain amount of lagging in the space lattice. The same thing is found in metals which have been to extremely low temperatures, such as liquid oxygen. We do not know positively whether that

(Continued on Page 1035)

A RAPID METHOD FOR THE HEAT TREATMENT OF THE ALUMINUM-COPPER-NICKEL-MAGNESIUM (PISTON) ALLOY

By Samuel Daniels

Abstract

The principles of heat treatment of the aluminum-copper-nickel-magnesium ("Y") alloy are outlined, together with the course of experimentation that led to the adoption of a two-hour treatment which increased the strength of the alloy as cast from 25,000 pounds per square inch to 35,000 pounds per square inch and the Brinell hardness from 74 to 105. The effect of time at soaking temperature, of quenching medium, of aging temperature and period, and the influence of cross-section upon the mechanical properties are discussed in detail.

THE aluminum-base alloy containing 4 per cent of copper, 2 per cent of nickel, and 1.5 per cent of magnesium[1] is being increasingly used for pistons, air-cooled cylinder heads, and other parts operating at elevated temperature. The preparation of the alloy is simple; the foundry technic required demands more care than that for the 92 aluminum-8 copper (Lynite 12) alloy, involving, as it does, the recognition of certain peculiarities of the material itself; its machinability is excellent; and its ultimate strength, proportional limit, and hardness at temperatures up to about 500 degrees Fahr., are, especially when heat treatment has been utilized, eminently satisfactory.

The full properties of the alloy are secured only after heat treatment. British investigators,[2] with heat treated, chill-cast rods 1 inch in diameter by 7 inches long, realized an ultimate strength of about 45,000 pounds per square inch and an elongation in 2 inches of from 5 to 6 per cent. The bars were heated at approximately 975 degrees Fahr. for 5 hours, quenched in boiling water and finally allowed to age at room temperature for 8 days before testing. A strength the equal of this, accompanied, however, by an elongation of 1.5 per cent has been obtained with sand-cast

[1]Institute Mechanical Engineers, Eleventh Report to Alloys Research Committee (1921).

[2]Rosenhain, Archbutt, and Wells. *Journal*, Institute Metals, Vol. 29, p. 191, 1923.

The author, Samuel Daniels, is Chief, Metals Branch, Material Section, Engineering Division, Air Service, U. S. A., McCook Field, Dayton, Ohio.

bars, 0.505 inch in diameter over the gage length, soaked at 975 degrees Fahr. for 96 hours, quenched in cold water and artificially aged at 300 degrees Fahr. for 8 hours [3]

Rationale of Heat Treatment

The heat treatment of aluminum-copper-nickel-magnesium castings may be conducted either in an air furnace or in a nitrate bath consisting of equal parts, by weight, of sodium and of potassium nitrate; and it embraces three operations: soaking at elevated temperature, quenching, and aging. When proper attention is paid to carrying out this schedule, the resulting hardness and tensile properties of the material will be uniform, granted that the alloy is initially of average homogeneity and soundness. The castings must be handled considerately during treatment. It is seldom that cracks occur from the quenching; usually it is found that these exist in the casting as it comes from the foundry floor.

Electric, gas, and oil-fired furnaces, muffle or semi-muffle in type, and the nitrate bath are employed for the soaking operation. Each has its particular advantages and disadvantages. The electric furnace, compared with the nitrate bath, is probably better adapted for long soaking periods, is less dangerous to handle, and leaves the castings cleaner and less liable to corrosion; on the other hand, the electric furnace, unless special arrangement is made for proper circulation, usually suffers from a temperature gradient, which is the more pronounced as the unit increases in size. The nitrate bath heats more rapidly and gives satisfactory temperature uniformity, but it presents the threat of burns from splashing salt and of contamination of the quenching medium by corrosive chemicals. For large pieces and heavy charges the nitrate bath is not so economically suitable as the electric furnace.

The control at the soaking or "solution" temperature of 950 degrees Fahr. should be to within ± 25 degrees Fahr. When the temperature is too low, the alloy does not harden fully; at the other extreme, which is in the neighborhood of 1000 degrees Fahr., the alloy begins to blister and melt. Proper temperature control is therefore necessary and pyrometric equipment, preferably with automatic regulation, is essential. It is best to have the furnace at the soaking temperature before the castings are charged.

Care should be taken not to injure castings during treat-

[3] Lyon and Daniels, *Journal*, Society of Automotive Engineers, Vol. 14, p. 173, 1924.

ment or manipulation while they are at the soaking temperature. Jostling and loading parts upon or against one another when they will not bear the weight without buckling should be avoided, and similar precaution should apply to the promiscuous use of tongs. The aluminum-copper-nickel-magnesium alloy withstands rougher usage with tongs than some of the other aluminum-base alloys which are heat treated. Pistons and air-cooled cylinder heads, especially the latter, are often removed from the furnace by gripping a heavy section. This procedure may often be feasible, because castings are generally heat treated before machining, sometimes thus to establish the growth occurring on heating to temperatures in excess of about 475 degrees Fahr. Mention should also be made of the distortion which may result from stress set up by quenching.

For quenching media, air, boiling water, cold water, and oil have been used. The heated castings should be transferred to the quenching medium as rapidly as possible. Air cooling is sometimes mandatory in order to avoid distortion. Cold water is often more convenient to use than boiling water; and oil is objectionable because it is difficult to remove.

After they have been quenched, castings are next aged. When the aging is allowed to take place at room temperature, the process is referred to as "natural" or "spontaneous" aging. This type of aging takes place relatively slowly, occupying a space of days. When speed of production is essential, it becomes more logical, though more expensive, to resort to "artificial" or "accelerated" aging, which has for its aim the accomplishment of the same ends as does natural aging, with the difference that the result is attained in a matter of hours by reheating the quenched alloy to a temperature generally less than about 475 degrees Fahr. and air cooling. The artificial aging process may be conducted in a chamber filled with live steam at the proper temperature. Ordinary electric or gas-fired ovens are also satisfactory. The prime requisites for the aging oven are simply temperature uniformity and temperature control to within, perhaps, 20 degrees Fahr.

Theory explains what happens during heat treatment by setting forth that certain metallographic compounds produced by the addition or presence of such elements as copper, magnesium, and silicon are to some extent dissolved by the aluminum at the

soaking temperature and are retained in solid solution by the quenching operation. The aging process then causes the reprecipitation of these soluble compounds in finely divided particles.

Present Experimentation

This article embodies the results of research on the curtailed heat treatment of the sand-cast alloy made by the Metals Branch of the Material Section at McCook Field. The objections to the protracted treatments previously mentioned are easily visualized. Ordinarily, too, there is no need to develop in the cast material a strength in excess of about 32,000 pounds per square inch provided the hardness requirements have been met.

At first the treatment used comprised a 5-hour soaking at 950 degrees Fahr., quenching in boiling water, and aging at 212 or 300 degrees Fahr. for 16 hours (over night), but after this schedule had been employed for a while an effort was made to make the castings available sooner. Attention was first directed to the aging process and it was found that by aging at 400 degrees Fahr. the direct total treatment period could be shortened to 5 hours. Practically at the same time tests were in progress to ascertain at exactly what temperature softening took place in the reheating of the hardened alloy[4] and these, together with the results of tests being made at elevated temperature, suggested that softening did not begin at 400 degrees Fahr. Investigation of this point led to the determination of the fact that the quenched alloy could be expeditiously aged at 450 degrees Fahr. The subsequent data describe the course of the experimentation.

Procedure

Air Service Specifications No. 57-72-1, to which the sand-cast aluminum-copper-nickel-magnesium alloy must conform, is as follows:

Chemical Analysis

	Per Cent
Copper	3.75-4.5
Nickel	1.75-2.25
Magnesium	1.25-1.75
Iron	0.75 (Max.)
Silicon	0.5 (Max.)
Other Impurities	0.25 (Max.)
Aluminum	Remainder

[4]Daniels, American Institute of Mining and Metallurgical Engineers. Paper 1519-E, 1926.

Mechanical Properties (After Heat Treatment)

Type Specimen	Ultimate Strength lbs. per sq. in.	Brinell Hardness 10-mm ball, 500kg. load, 30 sec.
Silicon		0.5 (Max.)
Cast-to-size (TB1)	32,000 (Min.)	90 (Min.)
Machined-to-size (TB1A)	29,000 (Min.)	90 (Min.)

The specific gravity must not exceed 290.

The cast-to-size (TB1) test specimen is green-sand cast in a mold of three, with a common pouring sprue at one end and individual risers at the other end. This bar is 0.505 inch in diameter over a gage length of about 2⅛ inches. The machined-to-size (TB1A) test specimen mold is like the TB1 mold, only the bars are cast to ⅝ inch in diameter over the gage length and are thereafter machined to 0.505 inch in diameter before testing. The TB7 test specimen mentioned in later paragraphs is cast two bars to the mold, with common pouring sprue at one end, a common riser at the other end. This bar is 15½ long by 1¼ inches in diameter and from its center was machined the TB1A test specimen, thus to give the effect of entire loss of skin and the extent of penetration of the very short heat treatment. The test specimens were poured, often with heats of pistons, from a temperature of 1300 degrees Fahr. The proportion of new ingot charged with gates ranged from 0 to 100 per cent.

The analyses of the several heats of ingot used follow:

Melt No.	Copper	Nickel	Magnesium	Iron	Silicon
		In Per Cent			
3786	4.13	1.79	1.38	0.58	0.24
3986	3.88	1.82	1.56	0.44	0.20
4248	4.01	2.15	1.45	0.48	0.18
4253	4.18	2.01	1.54	0.39	0.22
5021	4.36	2.29	1.44	0.49	0.28
5207	4.14	2.00	1.54	0.48	0.20
5411	3.73	1.84	1.56	0.44	0.18
5425	4.34	2.11	1.50	0.34	0.21

This ingot was made by melting down 99.0 plus aluminum (Air Service Specification No. 11,010, Grade A) and adding the proper quantity of 55 aluminum-30 copper-15 nickel hardener. When the hardener has melted, the bath is skimmed, and the magnesium is added just before pouring. The pouring temperature of the ingot was usually about 1350 degrees Fahr.

The test specimens were soaked at 950 degrees Fahr. in an electric furnace automatically controlled to within ± 7.5 degrees

Fahr. The charge was placed upon iron plates and loaded after the furnace had settled at temperature. The bars, following the soaking operation, were rapidly transferred to the desired quenching medium. Those which were not tested immediately after having been quenched were aged artificially at temperatures from 212 to 475 degrees Fahr. for various periods of time in an automatically controlled electric oven or, more generally, in a manually controlled, gas-fired oil bath. No specimens (TB1A and TB7) were machined to size (0.505 inch diameter) until after they had been heat treated.

The tension tests were made in a 20,000-pound Olsen machine and the Brinell hardness represents values for a 10-millimeter ball, 500-kilogram load, applied for 30 seconds. The results contained in the various tables are average for not less than three bars to the treatment. The Brinell readings were made on smoothly ground flats on the grip ends of the broken specimens with a specially designed micrometer microscope having a lateral traveling stage and registering on an Ames dial. The specimens consigned to immediate tension test after having been quenched were pulled as soon after the bars had cooled to room temperature as was possible, which was within 45 minutes. This delay was occasioned by the necessity for measuring the diameter of the bars and for stamping the gage points. A somewhat greater additional delay was imposed before the Brinell tests could be made.

Mechanical Properties

The results of heat treatment are gathered in Tables I to VII, inclusive. The significance of these data are the better appreciated when considered in comparison with the properties of the alloy as sand-cast. It has been shown[4] that the aluminum-copper-nickel-magnesium alloy has an ultimate strength of about 25,000 pounds per square inch, an elongation in 2 inches of 0.7 per cent, and a Brinell hardness of 75 a short time after having been cast. Subject to age-hardening at room temperature, the cast material six months later has given 28,410 pounds per square inch, 0.5 per cent elongation in 2 inches, and 96 Brinell hardness.

The initial experiments (Table I) disclosed that for a 4 or 5-hour soaking at 950 degrees Fahr., followed by quenching in boiling water (which was the first medium employed), artificial

[4] Loc. Cit.

aging for long or short periods at temperatures not higher than 300 degrees Fahr. gave a strength of about 37,000 pounds per square inch, 0.5 per cent elongation in 2 inches and 96 Brinell hardness. Aging at 400 degrees Fahr. for 2 and for 16 hours indicated the possibility of at least equivalent strength and greater hardness (105). The soaking period was therefore cut to 4 hours and the aging process set at 400 degrees Fahr. for 1 hour. This primary curtailment to a treatment requiring 5 hours for its completion did not fulfil the promise of increased hardness, but it speeded up the passage of castings from the heat treating department to the machine shop. The Air Service demands as to strength and hardness were met for quite a while with this 5-hour schedule, despite heavy dilution of the charge with gates.

Table II outlines the work undertaken with 450 degrees Fahr. as the aging temperature. The results showed conclusively that while the strength was hardly affected, the hardness was enhanced by from 5 to 10 numbers. An example is given wherein bars, quenched and aged at 400 degrees Fahr., were again aged at 450 degrees Fahr., with improvement in hardness from 102 to 110. At the same time, data were obtained for cold water and air quenching. The convenience of cold over hot water sponsored this test, with the indication that the former could be substituted for the latter without trouble. As was already anticipated, the air-cooling produced only 32,620 pounds per square inch, 0.5 per cent elongation in 2 inches and 96 Brinell hardness with 500-kilogram load. One hundred per cent of gates was used for the bars in this series of tests.

Since it was known that maximum precipitation was taking place in the neighborhood of 450 degrees Fahr., it was next attempted to shorten the soaking period at 950 degrees Fahr. A 1-hour treatment was sufficient (Table III) to develop a strength of 37,000 pounds per square inch, and the 2-hour treatment at 950 degrees Fahr., with the cold water quench and an aging at 450 degrees Fahr., once more manifested that the 450 degrees Fahr. aging made for a hardness (109) superior to that (99) engendered by aging at 400 degrees Fahr.

The effect of quenching medium, considering a 1-hour soaking at 950 degrees Fahr. and artificial aging at 450 degrees Fahr. for 1 hour, is to be noted in Table IV. The strength developed

Table I

Initial Experiments Upon Aging Temperature and Period

Melt Number	Charge Proportion	Type Specimen	No. Specimens	Heat Treatment	Average Mechanical Properties: Ult. Str. Lbs. Per Sq. In.	Elongation % 2 In.	Brinell Hardness 500 Kg.
4221	501-50G+	TB1	9	950-5BW-16++	37,010	0.5	97
			9	950-5BW-300-16	37,460	0.5	97
			6	950-5BW-2	36,940	0.5	96
			6	950-5BW-300-2	37,280	0.5	96
			6	950-5BW-400-2	36,680	0.5	105
			6	950-5BW-400-16	39,290	0.5	105
4248-57	151 to 1001	TB1	12	950-5BW-400-1-O°	37,410	0.5	98
4240, 4264	151 to 401	TB1	9	950-4BW-400-2-O	38,830	0.5	96
4237, 4258-70	151 to 501	TB1	27	950-4BW-400-1-O	36,520	0.5	98

+ I = Ingot; G = Gates.

++ Heated at 950 degrees Fahr. for five hours, quenched in boiling water and aged at 212 degrees Fahr. for 16 hours.

°When period at artificial aging temperature is followed by "O" it signifies that this aging was accomplished in oil, rather than in an electric oven.

Table II

Effect of Aging at 400 and at 450° F. After 4-Hr. Soaking at 950° F.

Melt. No.	Charge Proportion	Type Specimen	No. Specimens	Heat Treatment	Average Mechanical Properties: Ultimate Strength Lbs. Per Sq. In.	Per Cent Elongation 2 Inches	Brinell Hardness 500 Kg.
5113	100G	TB1	6	950-4BW-400-1-O	37,650	0.5	102
			6	950-4BW-450-1-O	35,440	0.5	109
			6	950-4BW-400-1-O 450-1-O	34,440	0.5	110
5350	.100G	TB1	6	950-4CW-400-1-O	35,880	0.5	93
			6	950-4CW-450-1-O	34,140	0.5	104
			6	950-4A-400-1-O	32,620	0.5	96

Table III

Effect of Time at Soaking Temperature

Melt. No.	Charge Proportion	Type Specimen	No. Specimens	Heat Treatment	Average Mechanical Properties: Ultimate Strength Lbs. Per Sq. In.	Per Cent Elongation 2 Inches	Brinell Hardness 500 Kg.
5404	100G	TB1	3	950-1CW-400-1-O	37,390	0.5	97
			3	950-2CW-400-1-O	38,440	0.5	99
			3	950-2BW-400-1-O	38,410	0.5	101
			3	950-2A-400-1-O	33,150	0.5	96
			3	950-2CW-450-1-O	38,910	0.7	109
			3	950-3CW-400-1-O	38,200	0.5	98
			3	950-4CW-400-1-O	35,460	0.5	97

Table IV

Effect of Quenching Medium in Rapid Heat Treatment

Melt. No.	Charge Proportion	Type Specimen	No. Specimens	Heat Treatment	Average Mechanical Properties: Ultimate Strength Lbs. Per Sq. In.	Per Cent Elongation 2 Inches	Brinell Hardness 500 Kg.
+	++	TB1	15	950-1A-450-1-O	32,480	0.5	96
			15	950-1BW-450-1-O	34,130	0.5	103
			15	950-1CW-450-1-O	36,590	0.5	106
			15	950-1O-450-1-O	36,780	0.6	102

\+ Melts 5448, 5467, 5471, 5474, 5481.

++ Latter four melts all gates; 5448 all ingot.

Table V
Effect of Quenching Operation in Rapid Heat Treatment

Melt. No. +	Charge Proportion ++	Type Specimen	No. Specimens	Heat Treatment	Average Mechanical Properties: Ultimate Strength Lbs. Per Sq. In.	Per Cent Elongation 2 Inches	Brinell Hardness 500 Kg.
		TB1	12	950-1A	30,920	0.6	90
			15	950-1BW	30,840	1.0	82
			15	950-1CW	27,530	1.9	77
			15	950-1O	32,420	1.0	87

\+ Melts 5448, 5452, 5458, 5460, 5480.
++ Melts 5452, 5460, and 5480 all gates; 5458 half ingot, half gates.

Table VI
Effect of Aging at Atmospheric Temperature After Quenching

When Tested	Heat Treatment: 950-1A+	950-1BW++	950-1CW++	950-10++
Immediately	31,060-0.5-92°°	29,420-1.0-80°°	27,510-2.0-71°°	30,680-1.1-82°°
7 hrs.		28,960-0.8-82	28,750-1.1-77	28,970-1.0-80
1 day	31,740-0.5-92	30,880-1.0-86	30,700-1.0-86	30,610-1.0-83
2 days		30,930-1.0-88	32,500-1.0-87	31,260-1.0-86
4 days		32,460-0.8-89	33,020-0.8-87	31,040-1.0-87
1 week	32,660-0.5-95	32,790-0.8-89	32,700-1.0-90	32,540-0.8-88
1 month	31,910-0.5-95	33,750-0.5-89	35,310-0.5-92	33,570-0.5-93°

\+ Melt 5448, average of 3 bars. ++ Melts 5480 and 5442, average of 6 bars, 3 from each melt, heat treated in different heats. ° Melt 5480, average of 3 bars only.
°° Ultimate strength—elongation—hardness.

Table VII
Effect of Cross-Section in Rapid Heat Treatment +

Heat Treatment	Type of Test Specimen: TB1	TB1A	TB7
950-1A-450-1-O	32,880-0.6- 99°°	31,050-0.5-107°°	26,990-O.S.G.*- 94
950-1BW-450-1-O	33,660-0.5-100	33,640-0.5-107	26,210-0.5-100
950-1CW-450-1-O	37,140-0.5-108	35,300-0.5-108	29,200-0.5-98
950-1O-450-1-O	34,280-0.5- 99	34,570-0.5-107	29,380-0.5-97

\+ Melt 5467, average of 3 bars except TB7, which are average of 2.
°° Ultimate strength—elongation—hardness.
* Broke outside gage marks.

in the alloy by quenching either in cold water or in oil is about 36,500 pounds per square inch, but boiling water and air are, in order, less effective media. In the case of air cooling, evidently a quantity of soluble compounds is retained in solution insufficient to enable any pronounced hardening through reprecipitation. As to Brinell hardness, cold water quenching is slightly more desirable than oil or boiling water quenching, which two, in turn, are appreciably preferable to air quenching. Oil quenching should be chosen as an alternative to cold water quenching when it is desired to minimize distortion of the casting. The results were

equivalent whether all gates or all ingot were used, and the data proved that it made no difference whether the test specimens were tested immediately after the artificial aging or 24 hours later.

Table V indicates the effect of the quenching operation itself, apart from any influence caused by aging. Immediately after quenching in air, boiling water, or oil, the alloy has an ultimate strength of about 31,000 pounds per square inch. Air cooling generates the highest immediate Brinell, 90, and boiling water quenching the lowest, 82. Strangely, after having been quenched in cold water, the alloy has an ultimate strength of 27,530 pounds per square inch, 1.9 per cent elongation in 2 inches and 77 Brinell hardness, which denotes quite a weak and soft condition, resembling, in strength and hardness, at least, the attributes of the material in the sand-cast state.

Age hardening at atmospheric temperature, following quenching, impresses over a period of a month a slow, but perceptible change in the tensile and hardness values of the alloy, except when it has been cooled in air (Table VI). When quenched in boiling water or oil, the rate and the extent of natural aging are practically the same. Upward of about four days is required before, with these media, aging brings the alloy to the point where it will meet the tensile minimum of 32,000 pounds per square inch prescribed by Air Service Specification No. 57-72-1. It is doubtful whether enough margin of safety is reached before one month has elapsed. Even then, the hardness conferred by artificial aging at 450 degrees Fahr. (Table IV) is not approached closer than ten numbers, and while the strength with the boiling water quenching and natural aging is the equal of that obtained from artificial aging, the same cannot be said of the properties ensuing from oil quenching.

When natural aging succeeds quenching in cold water, the alloy traverses the range of from 27,510 pounds per square inch, 2.0 per cent elongation in 2 inches and 71 Brinell hardness to 35,310 pounds per square inch, 0.5 per cent elongation and 92 Brinell hardness within one month. As with those just described, this difference is, of course, an effect solely attributable to the reprecipitation of dissolved compounds. The major portion of the increase in strength and hardness occurs in the first two days; thereafter the progress of aging is slow.

It is believed that, as a commercial practice, the substitution of the less expensive natural aging for artificial aging at 450 degrees Fahr. in the light of the postulates of Air Service Specification No. 57-72-1, is not to be recommended, especially when the castings must have a maximum of strength and hardness at once. It is further thought that while prolonged natural aging will result in the development of the strength given by artificial aging, regardless of quenching medium, the maximum of hardness is distinctly a peculiarity connected with aging at elevated temperature, presumably at 450 degrees Fahr., plus or minus 20 degrees Fahr., according to tests.

Finally, Table VII demonstrates the efficacy of the 950-1X450-10 treatment with regard to cross-section and loss of "skin". Using the cast-to-size (0.505 inch diameter) TB1 bars as the datum, the removal of $\frac{1}{16}$ inch of skin in the TB1A bars originally cast to $\frac{5}{8}$ inch diameter takes place with loss of considerably less strength than is occasioned in most aluminum alloys. The Brinell hardness seems to persist to a large degree even $\frac{3}{8}$ inch below the surface, in the TB7 bars. The strength of the 0.505 inch diameter specimens machined from these $1\frac{1}{4}$ inch diameter bars is 80 per cent or more of the strength of the TB1 test specimens, which is exceedingly good. The case for cold water and oil quenching over boiling water quenching is made stronger through the testimony of the greater strength of the core of these TB7 bars. Specimens from TB7 bars quenched in air and in boiling water are about as strong as the alloy in the cast state and those quenched in cold water and oil are approximately as strong and hard as the cast alloy after it has aged at room temperature for six months.

THE NATURE OF OIL HARDENING NON-DEFORMING TOOL STEELS

By Edgar C. Bain and Marcus A. Grossmann

Abstract

This paper presents some fundamental characterstics of the oil-quenching type of tool steels. Data offered were obtained from measurements of hardness, impact strength, change of dimension, and determination of X-ray crystal structure, as these properties are changed with various quenching and tempering temperatures. Deductions are drawn as to the preservation and subsequent destruction of austenite and this phenomenon is correlated with the practical behavior of the steel in its various uses.

THE present paper deals with some fundamental characteristics of a type of tool steel known generally as "oil hardening non-shrinking steel, or non-deforming steel." Such steels contain but a small amount of alloy; an amount, in fact, just sufficient to permit the more gentle oil-quench to be substituted in hardening for the drastic water-quench demanded by carbon steel. Oil quenching causes much fewer cracks and checks than water quenching, and steels thus hardened are freer from warping. Further, if a proper hardness results from an oil-quench applied to an alloy steel the hardening is much deeper than in carbon steel hardened in water.

The steels under consideration find their application in plug, ring and thread gages; both master gages and service gages of a variety of forms; delicate dies not subject to extremely severe use; and as master tools in shaping form tools when they are not in too frequent use. When plane surfaces of considerable hardness are to be attached to machines of various sorts these steels lend themselves admirably on account of their remarkable freedom from warping during hardening and the small amount of grinding required as a result.

The properties investigated and herein reported are the same

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. Of the authors, E. C. Bain is metallurgist at the Union Carbide and Carbon Research Laboratories, Long Island City, N. Y., and M. A. Grossmann is metallurgist with the Central Alloy Steel Corp., Canton, Ohio. Both authors are members of the Society. A large part of the experiment work herein described was carried out at the Atlas Steel Corporation, Dunkirk, N. Y., with which company the authors were associated during 1923-1924.

as have been studied by the authors for high speed steel, high chromium steel and fast finishing steel, and the paper may be regarded as one of a series covering a number of the typical tool steels. It is believed by the authors that the persistence of austenite and the manner of its decomposition, as much as any other single property in a steel, provides an index of its ultimate nature. In conjunction with some few data covering the gross properties of a steel under various heat treatments this information is extremely useful in determining its adaptability for any purpose. In the study of the tool steels, the authors have followed the effect of quenching temperature and subsequent tempering temperature upon hardness, impact strength, microscopic appearance, and change of dimension. This last property is in effect equivalent to density measurements. From a consideration of these series of physical measurements the temperature and rapidity of quench necessary to produce martensite and various martensite-austenite mixtures is revealed, and too, the stability or persistence of these constituents can be estimated.

The particular grade of tool steel to be discussed in this paper is exemplified by two different compositions which are, in general, maintained as follows:

	Steel No. 1	*Steel No. 2*
Carbon	0.85–0.95	0.85–0.95
Manganese	1.50–1.75	1.00–1.20
Phosphorus	Less than 0.020	Less than 0.020
Sulphur	Less than 0.020	Less than 0.020
Silicon	0.10–0.20	0.10–0.20
Chromium	None	0.40–0.55

Analyses of the particular steels used in these tests fall within the limits indicated above. It will be seen that the steel No. 1 depends upon manganese for developing the oil hardening qualities, while steel No. 2 is to a moderate extent a chromium steel, the chromium in this case facilitating the formation of martensite with the more gentle quench.

Although the amount of alloy is small, it is nevertheless a fact that (at the comparatively low temperatures employed at quenching) the scale formed is much thinner than usual. It seems surprising that such a small addition, especially of manganese, would serve to reduce the scale thickness so much. This condition reduces very appreciably the loss of dimension by straight

oxidation in the heating furnace. It is probably true that in simple shapes, the slight expansion of the metal itself in hardening is often just about equal to the thickness of this scale. When the scale is then polished off, the piece will have approximately its original size, with further accuracy available by the selection of a suitable tempering temperature. Such conditions, of course, make for a great saving of expense in grinding and polishing operations. There are other properties of these steels, however, which are responsible for their being chosen for certain specific purposes, and these properties have been known for some time. An attempt will be made in the present paper to explain the origin of these properties.

Hardness

Reference to Fig. 1 will show the slight effect that variation in quenching temperature has upon the hardness of steel No. 1 as quenched in oil. It appears that as soon as the piece has been heated sufficiently above the critical temperature to render it wholly austenitic and to produce a sufficiently high cooling rate

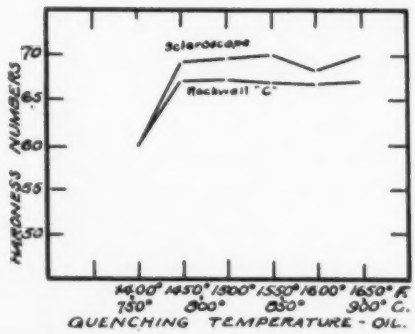


Fig. 1—Rockwell C and Scleroscope Hardness of Non-deforming Steel No. 1 as Affected by Temperature of Quench into Oil.

through this critical temperature in the oil bath, then a hardness is established which cannot be greatly increased (or decreased) by heating to a higher temperature. This observation leads up at once either to the conclusion that increasing the quenching temperature does not increase materially the amount of austenite preserved, or to the conclusion that the hardness of martensite-austenite mixtures in this particular steel is not greatly affected by change in the proportion of these two constituents. As will be developed subsequently, the second explanation proves to be

the correct one, and it is indeed a fortunate circumstance. The grain, either as observed under the microscope or as seen on the fracture, remains quite fine even in the specimens quenched from 1650 degrees Fahr. (900 degrees Cent.). The effect of tempering temperature on various quenches is illustrated in the charts of Fig. 2. The significant point of these charts is the remarkable

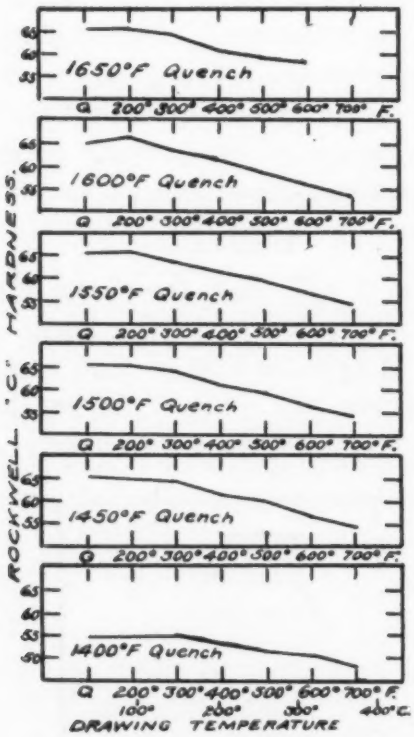


Fig. 2—Effect of Various Tempering Temperatures Upon the Hardness (Rockwell C) Obtained from Several Different Quenching Temperatures. Steel No. 1.

similarity of all the curves, showing more or less uniformly decreasing hardness with increase of tempering temperature. With the exception of the 1400 degrees Fahr. (760 degrees Cent.) quench, which was not from a sufficiently high temperature to produce completely hardened steel, the several tempering curves are essentially identical. It so happens that these hardness measurements were made entirely upon the manganese type of hardened steel, but judging from the similarity in their properties, it is expected that almost identical results would have been obtained from the chromium type of steels. Several isolated hardness measurements on steel No. 2, not sufficiently numerous to be

regarded as a series, checked the hardness values of No. 1 steel closely.

As in the earlier studies on tool steel the hardness values given are averages of closely agreeing Rockwell "C" tests.

Change of Length Caused by Various Tempering Temperatures

Examination under the microscope, and the fracture of many specimens of these steels reveals the fact that it is an extremely

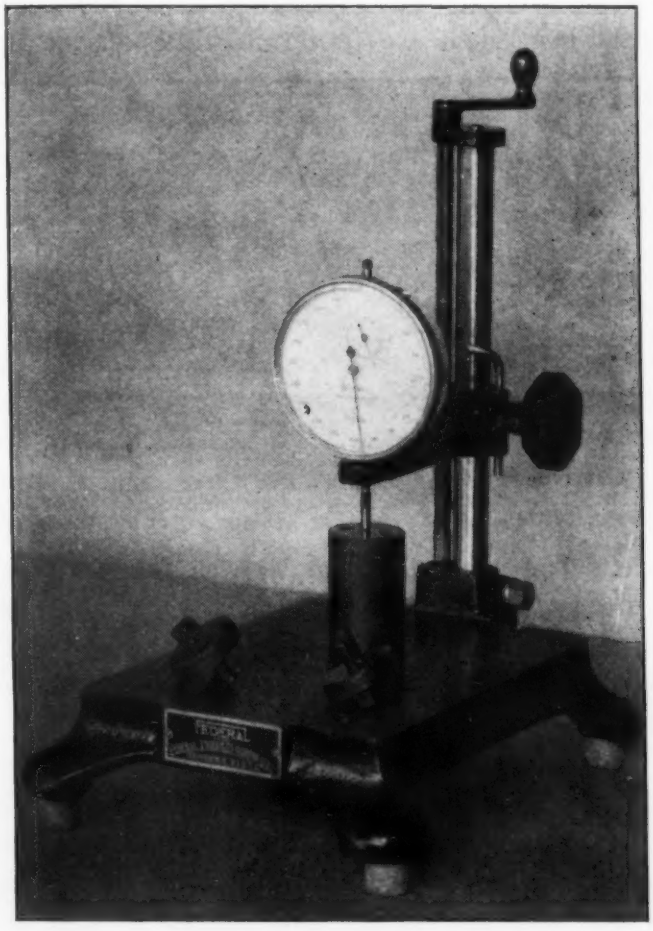


Fig. 3—The Length-change Measuring Instrument with a Specimen Uncapped and in Position for Measuring.

"deep hardening" material. Fairly large cylinders can be hardened to a depth which will permit length-change study with reasonable assurance that the over-all dimensions are changing in a manner quite representative of the entire mass under study. For the length-change study cylindrical specimens were made similar

to those employed for similar studies of high speed steels. The cylinders were about 2½ inches long and 1½ inches in diameter. Protective caps to prevent oxidation were bolted on to the specimens and even after the highest quenches, when the caps were removed the ends of the cylinders presented an essentially untarnished surface. The method was used first in connection with high speed steel, and no difficulty was to be expected in this study since the method had proven entirely satisfactory for the extremely high temperatures involved in high speed steel. Fig. 3 is a photograph of such a cylinder in place on the length meas-

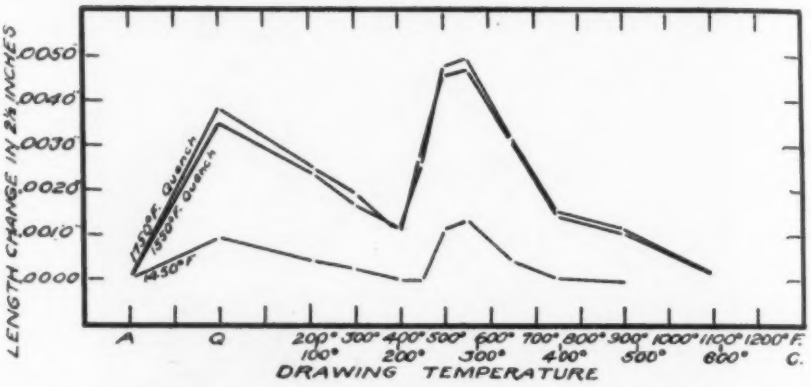


Fig. 4—The Change in Length of 2½-inch Specimen as Caused by Tempering at Various Temperatures. Steel No. 1; Quenched at 1450, 1550, and 1750 Degrees Fahr. (A Represents Length as Annealed, Q as Quenched.)

uring device. The change in length was followed by means of a Federal dial calibrated in divisions corresponding to one ten-thousandth of an inch. It is possible to estimate hundred-thousandths from the readings, but all averages are plotted only to the nearest ten-thousandth.

Fig. 4 shows the change in length in thousandths of an inch in specimens 2½ inches long for the manganese type of steel (No. 1) and Fig. 5 is a similar chart showing the measurements obtained for the chromium steel (No. 2). The two curves illustrate nicely the great similarity of the two alloys. It will be seen that a sharp minimum of length is obtained at about 400 degrees Fahr. (200 degrees Cent.) and that a marked maximum in length is produced by reheating to a temperature only 100 degrees higher or 500 degrees Fahr. (260 degrees Cent.). It will be noted that these characteristic expansions and contractions occur at precisely the same temperatures regardless of quenching temperatures. It will be noticed that the 2½-inch cylinders expanded with high

quench between 0.004 and 0.005 inch and with the ordinary quench between 0.001 and 0.0015 inch. That is to say, the linear expansion upon the quench ranges from .06 per cent to .2 per cent,

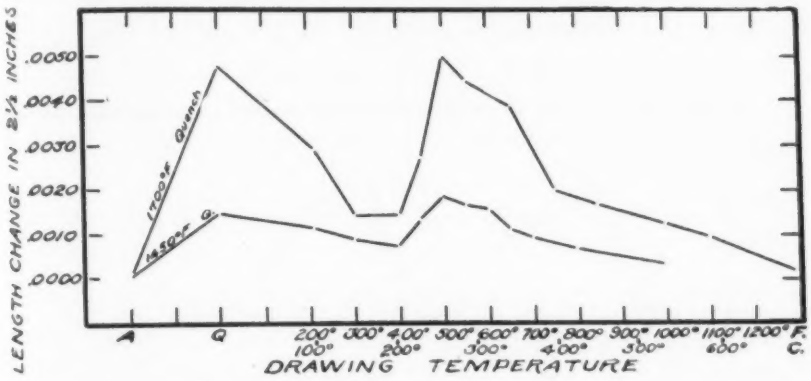


Fig. 5—The Change in Length of 2½-inch Specimen as Caused by Tempering at Various Temperatures. Steel No. 2; Quenched at 1450 and 1700 Degrees Fahr. (A Represents Length as Annealed, Q as Quenched.)

depending upon the temperature of the quench between 1450 degrees Fahr. (790 degrees Cent.) and 1750 degrees Fahr. (950 degrees Cent.). The pieces quenched at 1450 degrees Fahr. are probably hardened only part way through, so that the expansions and contractions take place only in an outer layer. The unhard-

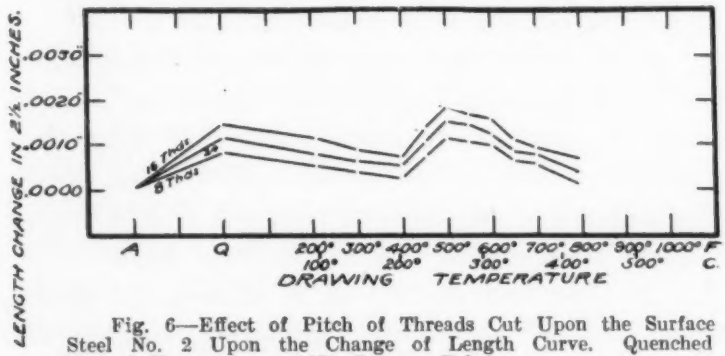


Fig. 6—Effect of Pitch of Threads Cut Upon the Surface of Steel No. 2 Upon the Change of Length Curve. Quenched at Normal Temperature—1450 Degrees Fahr.

ened center would have a restraining effect on the motion of this outer layer, so that the total expansions would be decreased. It will be seen that for both grades of steel the expansion at 500 degrees Fahr. (260 degrees Cent.) restores the steel almost exactly to the length acquired as a result of the quench.

As has been mentioned, these steels are much used for thread gages. This circumstance has led the authors to investigate the effect of variously threaded surfaces upon the change of length

in cylinders of the same size. The results portrayed in Figs. 6 and 7 show how little effect the various threads on the surface have upon the constituents formed in the specimens (either at the normal 1450 degrees Fahr. (785 degrees Cent.) quench Fig. 6, or at the high 1700 degrees Fahr. (925 degrees Cent.) quench, Fig. 7. It is quite likely that the unavoidable discrepancies

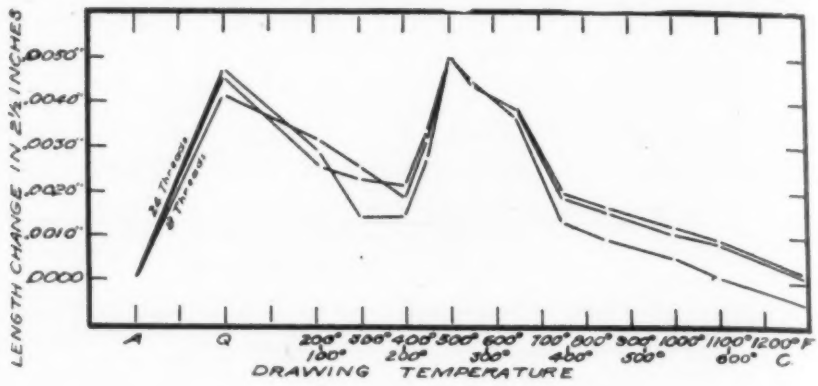


Fig. 7—Effect of Pitch of Threads Cut Upon the Surface of Steel No. 2 Upon the Change of Length Curve. Quenched at 1700 Degrees Fahr.

which creep into heat treatment experiments of this sort may be responsible for the differences rather than the threads themselves cut upon the cylinders. Only three different pitches were studies—8, 16, and 24 60-degree threads per inch.

So far as is known the only structural change in steels of this character which can account for an expansion upon reheating is the change of austenite to alpha iron. We have then almost uncontrovertible evidence that in these low alloy steels a very considerable amount of austenite is retained after the quench and that it is quite persistent up to 400 degrees Fahr. (205 degrees Cent.). Up to that temperature it is apparently stable, and is then released, sharply and quite completely, slightly above this temperature, as may be inferred from the very steep slope of the expansion curve up to a temperature of 500 degrees Fahr. (260 degrees Cent.).

Evidence is quite clear that the martensite of such steels is progressively decomposed into troostite, sorbite, etc. more and more rapidly as the steel is reheated to temperatures above 200 degrees Fahr. (95 degrees Cent.). Particular attention is called to the extremely rapid contraction which follows the austenite-alpha iron transformation at 500 degrees Fahr. (260 degrees Cent.). We

are able then with great assurance to point to these types as examples of steels wherein a generous preservation of austenite is entirely incapable of producing secondary hardness by tempering back to break down the austenite. This is illustrated in Fig. 2, which shows how the hardness decreases gradually and regularly. There are none of the variations which usually accompany the observed increases and decreases in dimensions and impact toughness. In fact, it may well be suggested, that the austenite preserved after the quench transforms directly into troostite or into a very transient form of martensite. At any rate, we are certain that whatever contribution to hardness is offered by the release of austenite at 500 degrees Fahr. (260 degrees Cent.), this contribution is not more than sufficient to make up for the rapid loss in hardness accompanying decomposition of the martensite produced at the time of the quench.

Impact Strength

The changes from brittleness to toughness in steels are in general so sensitive that the measurements of impact strength might be expected to cast some light upon what takes place structurally during the reheating of these alloys. Accordingly groups of five or six identically treated specimens were made up and broken—each group representative of one of a number of reheating temperatures, all having been quenched from 1425 degrees Fahr. (775 degrees Cent.) in oil.

On account of the susceptibility of impact strength measurements to the slight surface imperfections and other differences beyond the control of the heat treater, it has always seemed advisable to have a number of values for a single point which may be averaged in order to reduce experimental error. The impact values used in plotting Fig. 8 were obtained from ⅜ inch square unnotched bar on a Charpy machine. The departure of the individual readings from the reported mean is satisfactorily small. As might have been expected, the chart of Fig. 8 shows that the impact strength is at a maximum at about 450 degrees Fahr. (230 degrees Cent.) a temperature corresponding quite closely with the greatest preliminary shrinkage. The impact value falls off rapidly with a higher reheating temperature corresponding to the range of the destruction of ductile austenite.

Reheating of the steel to higher temperatures causes a very

rapid and enormous increase in impact strength, corresponding approximately to the condition of annealed steel. The impact value for 650 degrees Fahr. (345 degrees Cent.) is not shown on the chart, although measured, for the reason that it was rather too great to be plotted on the same chart with the others, and also because the individual values were somewhat erratic. It will be noticed in Fig. 8 that the impact maximum at 450 degrees Fahr.

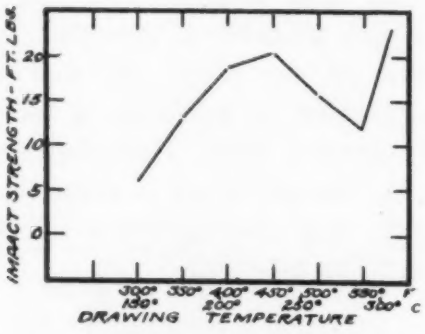


Fig. 8 — Charpy Impact Values on ⅜-inch Square Specimens of Steel No. 1 with Various Tempering Treatments. Quenched at 1425 Degrees Fahr.

(230 degrees Cent.) and the impact maximum at 550 degrees Fahr. (290 degrees Cent) both occur at a temperature about 50 degrees higher than that observed on the length change charts for what is believed to be the same condition in the steel. The explanation for this 50-degree discrepancy doubtless may be found in the circumstance that the length-change measurements must of necessity always be measured on the same bars successively reheated—the tempering effect being cumulative—whereas obviously the impact specimens have had but the single reheating. The time of holding the specimens at any given temperature was the same in each case—one-half hour.

The authors find a rather disturbing condition at the 550 degree Fahr. (290 degree Cent.) point which appears to be a very critical one for impact value. Regardless of the care to insure perfect duplication with which twelve specimens are heat treated, there is always considerable disparity in the impact for this particular tempering temperature. The values obtained may be grouped quite easily into two classes, high and low. This appeared to be a very discouraging circumstance, but it can probably be explained by the extremely unstable nature of the martensite pro-

duced by the decomposition of preserved austenite. If it remains as martensite, it will contribute greatly to brittleness, but in all probability at this relatively high temperature, the martensite is scarcely formed until it decomposes into the tougher troostite.

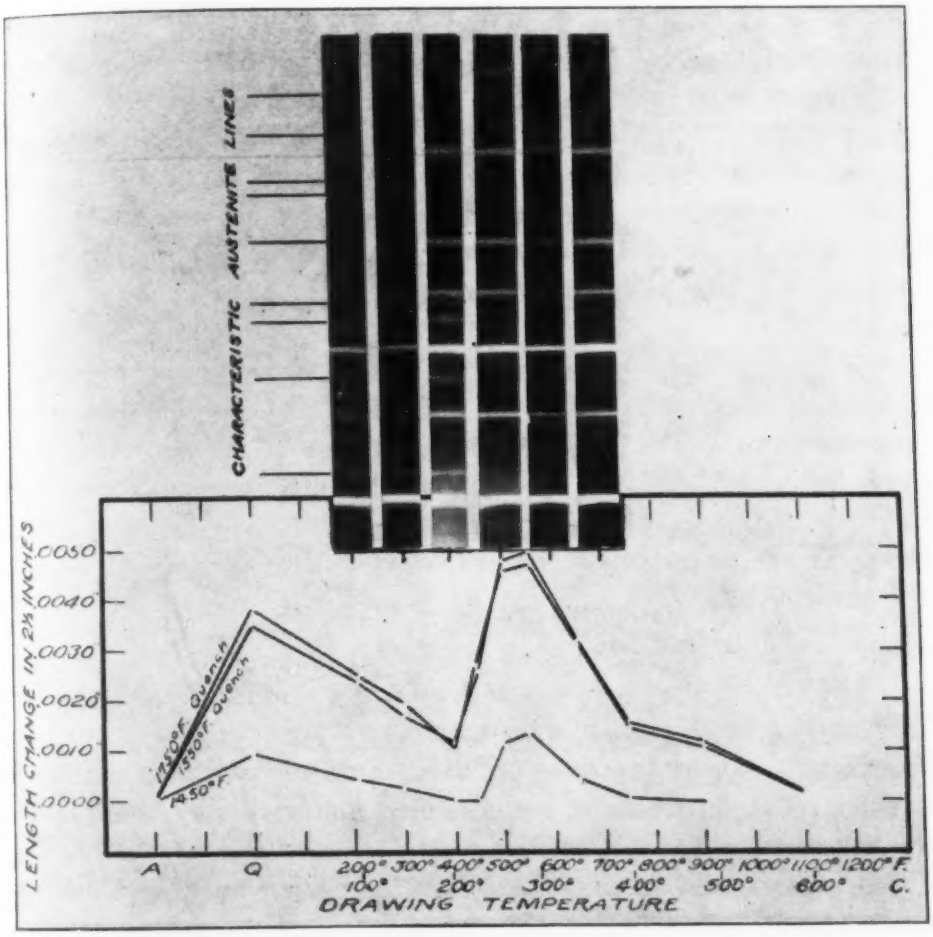


Fig. 9—X-ray Crystallograms of the Variously Tempered Specimens. Note Disappearance of Austenite Lines above 500 Degrees Fahr.

In the realm of heat treatment, experimental accuracy is scarcely great enough to obtain any large number of specimens in just the condition to show the brittleness of martensite. A few specimens will have continued the sequence of changes far enough to achieve a considerable impact value. Whether or not this is the correct explanation for the vagaries of the impact tests at the 550 degrees Fahr. (290 degrees Cent.) point, it does at least conform with the idea of the ephemeral nature of martensite produced by the decomposition of austenite in these steels.

X-ray Structure

Through the courtesy of the Union Carbide and Carbon Research Laboratories, Long Island City, N. Y., a number of X-ray crystallograms of steel No. 1 were made. Samples from the entire series of tempering temperatures were exposed—all quenched from 1600 degrees Fahr. (870 degrees Cent.). The three crystallograms from specimens tempered at 200 degrees Fahr. (95 degrees Cent.), 300 degrees Fahr. (150 degrees Cent.) and 400 degrees Fahr. (205 degrees Cent.) all showed easily recognizable austenite lines superposed over the alpha iron lines of the martensite. But no austenite lines are to be seen in the crystallograms of specimens tempered at 500 degrees Fahr. (260 degrees Cent.) or above.

For convenience, in Fig. 9, there are shown the crystallograms extending vertically above the temperature of tempering corresponding to each film. The disappearance of the austenite lines may easily be seen sharply between the 400 degrees Fahr. (205 degrees Cent.) and the 500 degrees Fahr. (260 degrees Cent.) tempering temperature. The characteristic expansion is shown on the same chart.

Conclusions

1. The addition of a small amount of alloy (e. g. 1½ per cent manganese or 1 per cent manganese with about ½ per cent chromium) causes the steel to harden deeply with the mild oil quench. The hardness is not modified materially by the quenching temperature employed.

2. These steels are softened by tempering back in much the same manner as carbon steels—irrespective of quenching temperature there is no secondary hardness to be observed.

3. Austenite is retained copiously in the steels when oil-quenched; the amount increasing with the quenching temperature.

4. The austenite of this class of steels is decomposed at about 450 degrees Fahr. (230 degrees Cent.) in the course of 30 to 45 minutes.

5. The dimensions of these steels—as for instance in carefully made precision pieces—varies markedly with the tempering temperature and without sacrificing hardness a proper tempering temperature can usually be applied so that the final size—cleaned of scale, is very near that of the original work.

The Authors

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M. A. Grossmann was graduated from Massachusetts Institute of Technology, 1911, then associated in various capacities with the Pittsburgh Testing Laboratory, Vanadium Corporation of America, U. S. Bureau of Standards, Electric Alloy Steel Co., Atlas Steel Corporation, and, lately, research metallurgist, and then metallurgical engineer of the United Alloy Steel Corporation, Canton, Ohio.

DISCUSSION

DR. J. A. MATHEWS: The authors of this paper have been contributing a very interesting and informing series of papers, of which this is not the least interesting, on various of the alloy steels. This particular paper illustrates something that I would like to call to your attention, namely, the lag, as we might call it, between the art and the science. This type of steel was produced first about 21 years ago, at least, in this country. It was at that time that "Ketos" steel was introduced, and its properties as outlined in this paper from a practical point of view and so far as its use value was concerned were known at that time. The explanation of what those practical properties were due to had to await for some of the work on retained austenite. The steel had "peculiar" properties of great practical value, but we didn't know why.

There is one idea that might be inferred, or one inference that might be drawn from this paper that I think we should also mention. We might infer that this steel can be handled rather carelessly and hardened over wide range of temperatures without much difference in the practical result. It is no exception to my favorite rule that constant conditions give constant results. The degree of expansion on hardening and the degree of contraction that will follow upon tempering will vary somewhat with those initial temperatures. I have noticed in some cases where experiments similar to Mr. Bain's and Mr. Grossmann's were carried on that the steel seems to actually undergo a contraction to somewhat smaller than its initial dimension, and in one case there seemed to be two temperatures at which it crosses that line. The curve for contraction actually goes below the base line, and at a little higher temperature, when expansion begins, it comes up; so, theoretically, there may be two points at which it attains its initial size.

I hope the authors will continue to give us papers of this kind on this kind of products.

M. H. MEDWEDEFF: I was very much interested in the paper by the two authors whose contributions are always of real interest. I am however surprised to learn that the authors found that the steel represented by the type analysis of their No. 1, "remains quite fine even in the specimen quenched from 1650 degrees Fahr." We find this statement contrary to our experience. Of all the so-called "brands" of the non-deforming tool steels, the straight manganese type are decidedly subject to overheating. We have learned this fact through considerable grief, through the loss of several tools and the quenching temperatures of these tools was but slightly over 1475 degres Fahr. An examination of the fracture in these failures revealed a coarse overheated structure.

On the other hand steels of the No. 2 type are almost fool proof in the hands of the average hardener, they can be heated to past 1500 degrees Fahr. without showing signs of coarsening of the grain and we have never had a failure in tools made from the latter type due to overheating. So that we feel much safer when we make a die of the No. 2 type, having the assurance that it will come out in one piece in case the heat treat man does not happen to feel so good, or the pyrometer is off 50 degrees Fahr. So that we are thoroughly sold on the preference of using non-shrinking steels with slight additions of

chromium and tungsten and preferably also vanadium. There is a well known steel approaching the type composition of No. 1, but has the decided advantage over it in that it has a small amount of vanadium in it, which makes it also less subject to over heating.

So that I would recommend to all manufacturers of the non-shrinking types of steel that the type composition include small amounts of chromium and tungsten and also vanadium or at any rate vanadium alone.

Author's Closure (Mr. Bain)

In closing, I wish to thank these gentlemen for their complimentary remarks and to say a word further about the expansion of the steel upon quenching. I think it might be possible to heat the steel in such a manner as to reduce the first expansion observed and increase the second. It would be accomplished by heating to the temperature of maximum carbon solubility just below the solidus. This would produce an austenite of maximum stability and consequently after the quench there would be less martensite in the resulting mixture. Austenite is comparatively dense, hence our original expansion might be less. It should be remembered that in the order of density we have the carbide phase, austenite, ferrite and martensite, the last named being the most voluminous. It usually happens with the carbides wholly precipitated in high carbon alloy steels that the ferrite plus carbide condition is more dense than any austenite which can be preserved at room temperature, but to summarize them, if we could contrive to increase the proportion of austenite to a very high value, then we probably should not observe very great expansion upon the quench. In that case, as Dr. Mathews pointed out, the release of the austenite at 400 or 450 degrees Fahr. would enormously increase the volume.

In reference to the discussion regarding coarsening of the steel during heat treatment, what we may find depends entirely upon time and temperature and this, in turn, upon the size of the work being hardened. If a long period of heating is required so as not to overheat the corners and delicate contours then probably time has elapsed at elevated temperature so that grain growth can take place excessively, but it has been my experience in general that this steel does not exhibit very strong tendencies toward exaggerated grain growth at proper quenching temperature.

In connection with the other suggestion, vanadium additions to this steel would, I should say, be valuable in small amount. Indeed I am of the opinion that such additions are not unknown at present. Tungsten, no doubt, contributes some beneficial properties also. As far as chromium is concerned we can infer something of the effect from consideration of the steel No. 2 in the paper. Chromium contributes to the preservation of austenite by an entirely different mechanism from that which enables manganese to preserve austenite. Fundamentally the chromium actually operates against a wide range of stability for austenite; it narrows the temperature range—being one of that class of elements which is more soluble in alpha iron than in gamma iron. Alloys containing chromium develop a reluctance toward any changes in this manner; a less drastic quenching permits the chromium bearing austenite once formed to be retained. However, chromium is a remarkable hardening agent in steel and no doubt increases resistance to abrasion.

ALUMINUM BRONZE—AN ACID RESISTING MATERIAL

By W. M. Corse

Abstract

The practically important aluminum bronzes are those containing less than 11 per cent aluminum. Sound aluminum bronzes have been available for industrial use only since 1913. They are extremely valuable in possessing—in addition to the tensile properties of medium steel—a far greater resistance to corrosion, wear and fatigue than such steel. Aluminum bronze may be forged and machined with practically the same equipment as for steel. With proper care and fluxes it may be welded. It is especially useful in the chemical industry, being only slightly affected by concentrations of sulphuric acid up to 75 per cent, and of cold hydrochloric acid up to 5 per cent.

Properly designed castings have been made to stand a hydraulic pressure of 1000 pounds per square inch.

ALUMINUM bronze is of comparatively recent origin. It was first prepared by Lord Percy, an English chemist, about 75 years ago. It was known as aluminum-gold at the time and was recognized as a valuable discovery, but the high price of aluminum made it impossible to produce the new alloy in commercial quantities, and for years it was regarded as a curious laboratory product rather than a commercial possibility.

A close study of the available bibliography covering the period discloses only vague references to the new alloy by various research chemists until 1887, when the electrolytic method of producing aluminum brought the price of the alloy within practical commercial bounds.

The beginning of the century found English, French, German and American metallurgists working on the new bronzes, and in the first decade of the present century Dr. Leon Guillet, a Frenchman, advanced a valuable premise which established a basis from which to work. His theory was, in substance, "that the copper-aluminum alloys which can be used industrially are those which contain less

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than 11 per cent and more than 94 per cent aluminum, i. e. those which occur at each end of the series." This premise has been generally supported by succeeding researches, particularly at the copper end.

The best piece of scientific research on the subject was carried out by Carpenter and Edwards in England and published as the eighth report to the Alloys Research Committee of the Institution of Mechanical Engineers of Great Britain in 1907. This was followed by a research on copper, aluminum and manganese alloys by Rosenhain and Lantsberry and published as the ninth report to the same institution in 1910. These two researches, particularly the eighth report, constitute two of the finest pieces of scientific work ever done on any series of alloys, and confer great credit on their authors.

Read and Greaves in England pursued other investigations on the effect of nickel additions, and in the United States the commercial development of the aluminum bronzes commenced actively in 1914. About 1916 aluminum bronzes containing iron as a normal ingredient were produced commercially. Several articles were contributed to the technical press on the subject by Corse and Comstock cooperating with Vickers.

The Societe des Alliages of Paris, France, has also carried on extensive experiments and recently has published a brochure on aluminum bronze which summarizes the results of experiments covering a period of years. Their conclusions and results today practically coincide with those obtained by other investigators.

It has been conceded and generally recognized that the alloys of high copper content have a broad field of usefulness and the researches of the metallurgists have disclosed the amazing fact that these bronzes apparently combine properties which usually occur separately in other metal. Among these properties are

(1) the mechanical characteristics of common steels,
(2) marked resistance to corrosion,
(3) resistance to wear and alternating stress, and to repeated shocks higher than steel of equal tensile strength.

With such a wealth of valuable properties it is not to be wondered at that scientific investigation of aluminum bronzes was undertaken seriously on a large scale. It was, however, necessary to overcome three major difficulties before a sound commercial pro-

duct could be produced at a reasonable cost. These were:

(1) shrinkage at solidification,
(2) gaseous discharges at the moment of solidification,
(3) the freeing of the alloy from alumina.

The second item—gaseous discharges at the moment of solidification—was especially difficult to overcome, and an American metallurgist, Vickers, ultimately discovered a method of removing gases from this metal thus permitting the production of solid castings. Vickers also discovered and patented an alloy of copper-aluminum containing iron which had superior properties to the binary alloy of copper and aluminum alone.

Prolonged researches on both sides of the Atlantic corrected these difficulties eventually, and sound aluminum bronzes of varying compositions were available for industrial use as early as 1913. About this same time metallurgists and manufacturers saw the broad field of usefulness of the new aluminum bronzes. In 1915 the Ford Motor Company adopted aluminum bronze for the worm wheel in their truck which came onto the market about that time, and fifteen million pounds have been used in that item alone.

With this impetus, research and development proceeded rapidly and was only halted by the continuance of the World War. When it was commercially resumed, after the cessation of hostilities, the trend was toward the production and perfection of corrosion-resisting alloys.

In 1925 the Duriron Company formed a subsidiary company known as the Alcumite Corporation for this purpose. The main activity of this corporation is the manufacture of corrosion-resistant metals particularly the aluminum bronzes containing iron and known as Alcumite. The basic rights to these metals are secured to them by the Vicker's patent mentioned above. The research department of that company is daily accumulating scientific and service data pertaining to these alloys. At this point it may be well to mention that these alloys of high copper content should not be confused with the aluminum bronze used for paint, which is a powdered metallic aluminum.

Aluminum bronze has several outstanding properties of which the most important is corrosion resistance. It has a tensile strength of seventy-five to one hundred thousand pounds per square inch; it can be forged, sheared, machined, and, in fact, fabricated with

practically the same equipment and tools as steel. In addition, it is available in almost all standard forms. In addition to being manufactured in the form of exhaust fans it is particularly adaptable to the construction of ducts for handling gases. Joints are made either by crimping or riveting and it is possible to solder the joints by the use of a special phosphor copper or to weld the heavier gages with an acetylene torch. These ducts have been installed in a sub-station battery room of one of the large power companies. Aluminum bronze fans and ducts are used in pickling rooms, storage battery rooms (where the hydrogen given off by charging the batteries entrains appreciable quantities of electrolyte), dry kilns, laboratories, and many other places.

Aluminum bronze plays an important part in the fabrication of crates, racks, and other equipment for pickling steel parts in sulphuric acid. Typical baskets for small forgings or stampings are of riveted construction made up of angles and perforated sheet. Many other types of baskets are used and may be made up of castings, rods, or woven wire. Large pickling racks for pickling steel sheets are usually composed of a single casting, sometimes weighing a ton or more.

Aluminum bronze is being cast or fabricated into various forms of chemical apparatus and is particularly desirable for the construction of stills, autoclaves, piping, valves, and a multitude of other equipment. One particular type of still is used in the manufacture of caproic acid which is highly corrosive and odoriferous.

The chemical and steel industries use wood tanks for handling muriatic or sulphuric acid. These tanks must be held together with rods, and frequently bolts and lag screws are used in their construction. Ordinary steel rods last only a short time and the practice of covering them with lead has not been satisfactory, due to the fact that the acid finds its way between the steel rod and the lead covering, and corrodes away the steel. This type of aluminum bronze makes an excellent material for tie rods, bolts, and other tank parts.

The filter press frame is another instance of the application of aluminum bronze to chemical work. Its resistance to acid solutions makes it a valuable addition to the available materials.

Aluminum bronze is readily produced in the form of scoops and shovels which are being used for handling copper and nickel

sulphate crystals saturated with acid and mother liquor, as well as for a wide variety of other acid salts and sludges. Under conditions where steel shovels last only a few days these scoops have shown no sign of corrosion or wear after six months' service.

Pumps, of course, are quite essential equipment in the manufacturing and handling of heavy chemicals. A typical example of a pump with the liquid end made of aluminum bronze is manufactured from the standard design of the American Steam Pump Company of Battle Creek, Michigan, and, together with a number of others, is in use in the water purification plant at Calcutta, India, handling water with a chlorine content of one part chlorine to one hundred parts water at a temperature of 100 degrees Fahr. Various other types of pumps are made, including single acting, rotary and centrifugal.

Standard gate valves are regularly manufactured and find a wide variety of uses, one of the most important of which is in handling sludge acids in oil refineries where very corrosive conditions exist and ordinary iron or brass valves last only a short time.

The largest field of usefulness so far for acid resisting aluminum bronze is with sulphuric acid. Experiments show that it is only slightly affected by a concentration of sulphuric acid up to about 75 per cent. Aluminum bronze is, however, never recommended unless the acid is cold or at room temperature, as a very marked action is shown with the use of more concentrated solutions. Experience has shown that the maximum corrosion occurs between ten and fifteen per cent concentration, but is so slight that, expressed in depth of corrosion per year, it would amount to only about fifteen thousandths of an inch.

Aluminum bronze is one of the best available materials for use with the weaker hydrochloric solutions, and at room temperature is only slightly affected by concentrations as high as 20 per cent. With boiling solutions aluminum bronze can be used satisfactorily with concentrations of 3 to 5 per cent and sometimes economically at slightly higher concentrations, although the corrosion increases materially with high concentrations of hot acid.

Aluminum bronzes of the proper chemical composition—say a copper base with some 7.5 to 10 per cent aluminum and about 3 to 3.5 per cent iron with small amounts of manganese and nickel added, depending on the purpose for which they are intended,—

are inherently resistant to a wide variety of corrosive influences, but to obtain the maximum resistance the utmost care must be taken to insure correct and uniform analysis and sound homogeneous castings.

Interest in the subject of corrosion has become increasingly evident, if one may judge from the numerous articles appearing in the technical papers in the press. Various technical societies have conducted symposiums on the subject in the last few years, and several new and valuable books have been published recently or are on the press at the present time.

The interest in the subject mentioned above, has, however, stimulated research which has resulted in a much clearer understanding of the fundamentals of corrosion. This, in turn, will inevitably lead to commercial development which furnishes the practical man his reason for supporting research in pure science.

We have traced the development of aluminum bronze from its discovery in 1855 by Lord Percy until the present day. Foundries in the United States, Europe, Great Britain and Japan are producing aluminum bronzes of slightly varying compositions that resist corrosion to a greater or less degree. There remains, however, the none too easy problem of production and design, for the alloy in ingot form is of little more use to industry than was the old original aluminum bronze of Lord Percy's discovery. Production and design problems are being faced by all users of the new aluminum bronzes.

Production and Design Problems

Usually it is a difficult matter to prevent porosity in making castings of aluminum bronze. This has been largely overcome through the development of the specific alloys and through working out of special foundry practices. Castings, when correctly designed, can be poured to withstand a hydrostatic pressure of 1,000 pounds per square inch.

Design is an important factor owing to the tendency toward high shrinkage and rapid setting from the molten point even when poured at about 2150 degrees Fahr.,—the correct pouring temperature. Setting begins to take place at approximately 1850 degrees Fahr. The castings should be as nearly uniform in thickness as possible, and where it is necessary to change sections the change

should be gradual. Bosses, heavy ribs and other characteristics of design that necessitate unusual volumes should be avoided.

It is advisable to keep the minimum section at 3/8 inch or thicker in order to insure pressure-tight castings. Castings so designed that the metal must flow through the mold for any considerable distance is not good practice. The flowing molten metal has a tendency to form oxides which are apt to result in segregation of dross and, in consequence, porosity results. In some instances it is advisable to change patterns that are submitted for castings in order to provide for gating that will insure an adequate flow of metal into the body of the mold.

These points are mentioned more to bring out the importance of correct design and the fact that conditions peculiar to certain of the aluminum bronzes must be observed to get results.

Machining involves consideration similiar to those for a medium carbon steel, though a slightly longer time element is involved than is the case with either steel or ordinary 88-10-2 bronze. A cutting speed of approximately 80 feet per minute is good practice. Apparently a carbon steel works to better advantage when it is given plenty of clearance and is kept sharp.

The new aluminum bronzes are readily forgeable, but they require a somewhat different treatment than either steel or other nonferrous metals. The power required for rolling it is 40 to 50 per cent in excess of that needed for a corresponding reduction of carbon steel, but it can be rolled into shapes or drawn into wire as small as 0.005 inch. Spinning and drawing are possible to an unusual depth, but here again the longer time element must be observed in obtaining proper results.

The welding of aluminum bronze is more difficult than welding either brass or copper because of the presence of a film of aluminum oxide on the surface of the material. It is difficult and often impossible to reduce this film and it must, therefore, be fluxed off. The oxyacetylene process has been tried and found to work fairly well when proper care and fluxes are used. The hydrogen arc welding processes, utilizing atomic hydrogen, seem to hold the most promise, and quite satisfactory experimental welds have been produced by them.

The welding of aluminum bronze is still somewhat in the experimental stage, but, even so, satisfactory welds can be pro-

duced for certain types of work at the present time.

Aluminum bronze has one particularly advantageous trait in that equipment, at present manufactured from other materials, can be built of it with minor changes of design only plus slight changes in total equipment. Many standard pieces of equipment are now being entirely manufactured of aluminum bronze, using die tools and other production equipment originally designed for steel.

One outstanding advantage of constructing a machine (including bolts, rivets, or small parts) entirely of one material, especially where resistance to acids and other corrosives is of prime importance, is that the possibility of electrolytic action is avoided.

As yet, the aluminum bronzes are not well known, but engineers are beginning to find out that a bronze with the strength of steel is available and new uses are being found for it every day.

As set forth above the outstanding uses for aluminum bronzes are for corrosion resisting apparatus, for structural parts requiring resistance to fatigue, and for machine parts to resist wear such as worm gears. Aluminum bronze has also proved satisfactory for certain types of acid valves and for parts requiring strength exposed to sea water such as rudders, propellers, pumps and engine base castings.

Like all other metals that are being put to new uses, the aluminum bronzes present the problem of when and where to use them in equipment, but preliminary trials in new fields will usually indicate the direction of its best application.

DESULPHURIZATION

Slags, Fluxes and Desulphurizers

By E. J. Lowry

Abstract

The author in this paper discusses slags, fluxes and desulphurizers and is of the opinion that a secondary function of these three factors is temperature which plays a most important part. The writer sets forth by means of tables and a resume exactly what work was performed and what fluxes were used in the production of the report given. He is of the opinion that the conclusion of all of the subject matter contained in the paper may be drawn from those statements surrounding the chemistry of the slag and the fluxes used to dissolve the refractory compounds. The fluxes have definite lines which divide them into the classes which produce (1) proper slags; (2) proper slags combined with an efficient desulphurization; and (3) improper slags. The paper contains certain experiences, results and conclusions which the writer feels may be of interest and value to future investigators.

Preface

THE three sub-titles of this paper are essentially correlated due to the fact that one without the other cannot be perfectly attained. The secondary function of these three is temperature which is a formidable part in the production of a finality. In other words, the equilibrium of a slag is produced by fluxes, which react in the mode of desulphurization but whose efficiency is determined by the temperature thereof. In order that a complete knowledge of the disposed facts may be had, one must pursue the adequate reasons and examples of slags and fluxes that conclusions may be drawn in the desulphurization of steel.

Object

The object of this paper is to set forth certain experiences and other efforts which will perforce give to future investigators

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certain figures and results on which to work. The results are far from complete but they interlace with other investigations, thus making them of some constructive value.

The action of the Elements and the Slag

The first definite relation in slags is that of the "acids to the bases." This is an essential feature which one must bear in mind as regards desulphurization as well as physical consistency. It is a known fact that where the acids are "high" the power of desulphurization in a slag is low. Therefore the first principle in a desulphurizing slag is to have the bases in preponderance. But the action of acids to bases does not end at this point. Around them revolve the question of fluidity or viscosity of the slag and further the purity of the steel in accordance with the slag analyses.

The physical qualities of a slag are dependent upon its chemical analysis plus the temperature. Upon the former also depends the ability of a slag to perform certain requisites. We must therefore take up in a limited manner the elements in slags.

There have been various attempts to study slag reactions and the elements. The elementary reactions which are involved may be expressed as follows:

(1) $Si + 2FeO \rightleftarrows SiO_2 + 2Fe + 65$ Calories
(2) $2P + 5FeO \rightleftarrows P_2O_5 + 5Fe + 37$ Calories
(3) $Mn + FeO \rightleftarrows MnO + Fe + 26$ Calories
(4) $C + FeO \rightleftarrows CO + Fe - 36$ Calories

The following reactions which are secondary may be set up according to

(5) $C + MnO \rightleftarrows CO + Mn - 63$ Calories
(6) $2P + 5MnO \rightleftarrows P_2O_5 + 5Mn - 94$ Calories
(7) $5C + P_2O_5 \rightleftarrows 5CO + 2P - 220$ Calories

The slagforming compounds expressed in their possibility to have reactions which profoundly influence the manufacture of steel may be as follows:

(8) $2CaO + SiO_2 = 2CaO.SiO_2$
(9) $4CaO + P_2O_5 = 4CaO.P_2O_5$
(10) $SiO_2 + 2CaF_2 = 2CaO + SiF_4$
(11) $2CaF_2 + 2SiO_2 = SiF_4 + Ca_2SiO_4$

An almost indefinite number of reactions may be written for calcium fluoride (CaF_2) in slag but those expressed in (10) and (11) will serve the purpose for this discussion. Calcium oxide and calcium fluoride are shown here because they are the fluxes now in

prominent use in the steel making industry. The calcium oxide may be used as such (burnt lime) or it may be charged into the furnace as the carbonate, which is the most common method, and calcined in the furnace. The result of this is to cause the following reactions to take place:

(12) $CaCO_3 = CaO + CO_2$
and (13) $CO_2 + C = 2CO$

The latter is an important reaction from the standpoint of the furnace charge because it requires a higher carbon metal to be used on the intial charge when compared to the burnt lime heat.

The lesser known fluxes such as those of the sodium base, when used, may have the following reactions.

(14) $Na_2CO_3 + SiO_2 = Na_2SiO + CO_2$
(15) $4NaF + 3SiO_2 = 2Na_2SiO_3 + SiF_4$

According to Colclough, the first three reactions given in this set are "balanced" and capable of reversing their direction. As he states "(a) the reactions may proceed, not to completion, but to an equilibrium or even be reversible, (b) secondary reactions may be set up between different constituents of the system, (c) definite chemical compounds formed by secondary reactions may interfere with the progress or equilibrium of the primary reactions." Further, because of these conditions, the solution of the problem lays in determining (1) the state of equilibrium of these reactions and their constants; (2) the influence of the various factors upon these constants and on the rate at which the reactions occur. "The constitution of the slag is probably the most important factor controlling the main reactions (1) to (7)."

In proving his contentions he ran a series of tests which were not isolated and from which he extracted three class examples (1) a heat with a "thin" slag, i. e., one of low basicity; (2) a heat with a "very thick" slag, i. e., one of high basicity and (3) a "medium" slag, i. e., between the extreme limits of 1 and 2. The carbon and phosphorus contents at the beginning of the heats were:

	Carbon Per Cent	Phosphorus Per Cent
1	1.40	0.320
2	1.38	0.600
3	0.40	0.196

As heat No. 1 proceeded with additions of tap-cinder the phosphorus dropped from 0.32 to 0.21 per cent while the carbon fell

from 1.40 to 0.10 per cent. In the second heat, with no ore or cinder additions, the phosphorus dropped to 0.030 per cent while the carbon was only removed from 1.38 to 1.03 per cent. The third heat experienced a constant fall in both elements, the carbon going from 0.40 to 0.14 per cent as the phosphorus went from 0.196 to 0.090 per cent. The conclusions drawn from this experiment are: "Consideration of these facts shows that, although from thermo-chemical data it would be inferred that the oxidation of phosphorus would precede carbon, in practice the relative rates of oxidation of carbon and phosphorus depend, primarily upon neither thermo-chemical nor mass considerations but upon the composition of the slag, the controlling factor being the presence or absence of basic oxide to combine with P_2O_5 as it is formed." Inasmuch as the oxidation of phosphorus and its subsequent joining with the calcium oxide has an important bearing on the slag consistency, the expressed feature of Colclough's paper has been mentioned. The fact that medium and heavy amounts of lime are required to hold this impurity in the slag after oxidation and these weights are in proportion to percentages of the element present in the metal charge, the volume and consistency of the slag is again influenced by the phosphorus.

Inasmuch as the basic open-hearth process of manufacture of steel and the building up of a proper slag is essentially one of oxidation plus the type of charge, the solution seems simple. The oxidizing materials used are iron ore and the gaseous flames passing through the furnace. The carbon dioxide from the breaking up of the limestone also aids in this function, seeming to especially relate itself to action with the carbon.

This latter material does not materially aid in the building up of the slag volume. Dichman states that because of this element prolonging the heat and causing deterioration in the furnace structure the slag volume is increased 2.15 per cent. This may or may not be a hypothetical conclusion. The real slag builders are silicon and phosphorus. It has been shown that 1 per cent of silicon in the charge yields 10.23 per cent final slag while 1 per cent of sand (SiO_2) on the material charged produces an additional 4.78 per cent. It has also been found that for each 1 per cent of phosphorus there will be 5.9 per cent of final slag. Colclough's recent experiments check very closely to the percentages given even though they

are of long standing.

There are three other functions of a slag which may be mentioned here, (1) the relation of manganese, (2) the holding of sulphur and (3) the iron oxide content. It has been found that the distribution of manganese cannot be determined by any simple factor but is the result of a number of reactions of which the basicity and iron oxide values of the slag are important factors. From researches and practical experience it has been shown that the higher the base in the slag combined with a low amount of FeO, the greater the reduction of manganese by the carbon. In such instances the manganese is left free in the bath to aid in "killing" the heat as well as in desulphurization. Consequently, an effective desulphurizing flux must not be overestimated in its total ability due to this latter effect. The ability of the flux to desulphurize may be limited by the following theoretical equation.

$$MnS + FeO = FeS + MnO$$

When such an action takes place, the desulphurizing power of the bath becomes nil and if at this point a flux continues to lower the sulphur, it becomes an active agent. If the manganese is successful in combining with sulphur, the compound MnS rises to slag where it may be there oxidized to MnO and SO_2. The latter will escape to the stack of the furnace. These phenomena will only occur, however, when the FeO is extremely low in the slag.

The oxides of iron are introduced in the furnace as corroded material, cinder or mill scale, iron ore. It has been definitely shown that the addition of such oxides give a thinning effect to the slag. An excellent example of the reaction which takes place is shown in the reheating furnaces of rolling mills. The condition in such a case, is the combination of the silica sand floor with the mill scale falling from the ingots, a very fluid slag results when the combination of two takes place. But the oxide is not used for the purpose of obtaining good slag viscosity. Rather it is used to oxidize the elements as shown in the first group of four analyses. From what has been shown in the cases of sulphur and manganese, it becomes important then that the amounts given to the bath should be limited to the requirements of oxidation of the impurities. In the slag the oxides may be present as either FeO and Fe_2O_3 or FeO / Fe_2O_3. There seems to be no fixed relation between the two.

In all of the heats performed in this experiment as well as others the ratio of one to the other changed as the CaO content grew and the slag thickened.

An important experiment which was performed to show the effect of acids on the per cent of iron in the slag is given below:

Iron in Slag Per Cent	(SiO_2/P_2O_5) Per Cent
16.59	15.255
13.85	15.70
12.30	16.95
12.25	17.10
12.08	17.15
11.40	18.35
11.00	18.90
10.68	22.10

Iron in Slag Per Cent	CaO MgO SiO_2/P_2O_5 Per Cent
16.59	3.21
13.85	3.21
12.30	3.10
12.25	3.01
12.08	3.01
11.40	2.90
11.00	2.78
10.68	2.33

This experiment also immediately shows the effect of alterations of acids to bases and the effect upon the iron in the slag. This relation of acids to bases plays an important part in the effectiveness of a slag as regards its viscosity and its power to desulphurize.

It may seem rather strange that the discussion given is the preface on fluxes and desulphurization but experience has shown that without a slight knowledge of the reactions of the steel making process in relation to slag a misconception of fluxes and desulphurizers may easily be had.

The conclusions from this substance which bear upon the subject of fluxes and desulphurizers follow:

1. The slag volume is influenced by the chemistry of the metal charged, i. e., the higher the phosphorus and silicon, the higher the lime volume.

2. The viscosity of a slag is related to "acid" and "base" ratio, i. e., the greater the basicity, the thicker the slag in the basic process and vice versa in the acid process.

3. The viscosity of slag is also changed by the iron oxide present.

4. The sulphur reduction is a function of the reactions of

manganese which is restricted by the iron oxide present in the slag.

5. The "working" of the heat is directly related to the slag analysis.

Fluxes

A flux is used in the basic steel making process to give a fluidity to the slag of such a nature that it will drain easily from the furnace. The properties of a flux should be, (1) that it produce a slag having a low freezing point; (2) that it have a chemical composition of great activity; (3) that its weight per cubic inch be heavy; (4) that it carry some amount of moisture (the flux should not dissolve readily in water); (5) it should not volatilize readily or give off fumes and (6) it should not have any great power to attack the brick work of the furnace.

The most commonly known fluxes are (1) calcium fluoride (fluorspar); (2) calcium chloride and (3) sodium aluminum fluoride (cryolite). Of these, fluorspar is the one which is most widely used. Such fluxes are used to lower the freezing temperature of the slag and to aid in desulphurization. The amount used per heat varies with work required performed on the slag. Some heats will require no flux while others take heavy quantities.

This variation is largely due to the compounds in the slag. These compounds include the system CaO, FeO, SiO_2 which is the most important one. The way calcium fluoride acts on this system is a good illustration of the reason for the use of a flux. The fluorspar is usually added after all "the lime is up" and the time is right to prepare for a finishing slag. The lime rising to the slag from the furnace bottom, comes up in lumps and remains in "island" formations unless the temperature is high enough, or some fluxing material is used, to "smooth" out the slag. The amount of fluorspar used to perform this work varies from none per ton to as high as 20 pounds per ton. The average amount of fluorspar used per ton of steel (not ingot production) produced is about 6 pounds. This figure is computed on the yearly production of steel and the yearly consumption of fluorspar.

The fluorspar is shovelled into the furnace and aimed to land upon the thick points of the slag as well as the islands of lime. It usually requires from 2 to 5 minutes, depending upon the temperature, for the reaction of the fluorspar with lime. Just how the fluorspar acts is a subject of debate. There is no common agree-

ment among scientists and little concrete data to work from. Some say that the fluorspar reacts in accordance with equation (10). They reason that if this is true the silicon tetrafluoride (SiF_4) is volatilized and lost. It hardly seems possible that the most acid part of the flux, fluorine, should be lost leaving lime to increase the basicity which means the viscosity. It is known, however, that some of the fluorine is lost but the amount is an uncertain quantity.

Another theory is that reaction (10) does take place and that the SiF_4 is not lost, but that reversible actions are continually taking place between the calcium, silicon and fluorine. There is no way to prove or disprove this idea. It is an explanation.

An opinion which explains the action of fluorspar on the lime in the slag follows: In some instances fluorspar is added to smelting charges. Fluorspar which at 2512 degrees Fahr. (1378 degrees Cent.) is very fluid when melted, and assists in dissolving refractory slag constituents. With $CaSiO_3$, e. g., melting at 2733 degrees Fahr. (1501 degrees Cent.) it forms a eutectic with 38.2 per cent CaF_2, freezing at 2066 degrees Fahr. (1130 degrees Cent.). The reaction $2CaF_2\ 2SiO_2\ SiF_4\ Ca_2SiO_4$ by means of which volatile SiF_4 is to result, is of little, if any, importance.

This explanation seems to logically hold in the basic open-hearth practice because what actually happens when fluorspar is added to a basic slag is that the latter becomes thin and has a lower freezing point. It would be relatively easy to prepare a "finishing" slag, if its chemistry and temperature remained constant. These factors are variable, however, and make the preparation difficult. As the temperature increases, the viscosity of the slag decreases. Ledebur also states that the higher temperatures in basic practice increases the bases and decreases the acids. There is no available data which might be positive on the score. The changing chemistry of the slag is caused by "cutting of the banks" of the furnace which has MgO and CaO in its component parts.

A fluid slag will absorb both MgO and CaO from the lining. Consequently even after a finished slag has been prepared there is a danger of absorption of these two compounds with a resulting stiffening of the slag. When a slag holds nearly 60 per cent CaO and 40 per cent SiO_2 it will tend to become solid and inactive at open-hearth temperatures of about 2912 degrees Fahr. (1600 degrees Cent.). If the SiO_2 is increased the viscosity decreases. If

the SiO_2, however, is decreased particles of CaO will be seen to float on the surface. Of course, in practice, slags contain varying amounts of the more fusible bases, MnO and FeO, which act alike in the production of viscosity.

According to Colclough and Hoffman, the melting point remains quite low until the CaO reaches 40 per cent. After this point it rises rapidly. The effect of increasing the FeO and lowering the CaO in a viscous slag of 60 per cent CaO and 40 per cent SiO_2 is to lower the temperature to 2354 degrees Fahr. (1290 degrees Cent.) when 16 per cent of the iron oxide has been reached. This slag will be fluid and attack the banks, eating the CaO in order to reach its balance. Thus the SiO_2 and FeO are decreased by dilution and with increased FeO present the SiO_2 will be less. Campbell and others concur in pointing out that with less SiO_2 the FeO increases as opposed to CaO.

Another feature which influences fluidity is the ever changing amount of P_2O_5. There is no accurate data on the freezing points of this acid combined with CaO but it is certain that it produces a fluid melt. There is a relation of P_2O_5 to SiO_2 which governs, i. e.; the lower the SiO_2 the higher the P_2O_5. Hence, a changing fluidity and these causes show why the results are so varying in slag production.

Fluorspar is also used to accelerate desulphurization. (This will be discussed in the next part of this paper) and because of this, the question of sulphur in fluorspar pointedly arises. It is almost impossible to definitely say that the sulphur does or does not go into the steel when it is present in fluorspar. There are too many uncontrollable variables which lend to sulphur increases that make an experiment of little value unless it is carried out over a long period. It might be of some interest, however, to incorporate in this paper a test which was conducted to determine the effect of sulphur in fluorspar where this element was purposely increased. The data shown are not from isolated heats but represent a few extracted for the purpose of information. There were certain variables such as difference in time caused by delays waiting for hot metal, amount of ore additions, the use of cold pig iron on the start and the quality of the scrap. The size of charge, the fuel (producer gas), the lime charge and the furnace was constant. The results are shown in Table I.

Table I

Analysis of Heats

No.	Heat No.	Sulphur in Fluorspar	Pounds of Fluorspar Used	Time Hrs.-Min.	Sulphur Analysis					Final Analysis			
					Tests Taken Before Each Fluorspar Addition					C	Mn	S	P
1	1334-Y	0.50	300	10 47	0.044	0.041	0.045	0.037	0.040	0.12	0.47	0.040	0.08
2	3267-Y	0.50	900	10 30	0.046	0.049	0.046	.....	.....	0.09	0.54	0.046	0.11
3	1336-Y	0.10	1000	11 25	0.046	0.045	0.041	0.043	0.040	0.18	0.49	0.041	0.09
4	4289-Y	0.10	875	12 05	0.048	0.047	0.044	0.043	0.043	0.18	0.57	0.043	0.10
5	6357-Y	1.00	650	8 51	0.047	0.043	0.040	0.044	0.040	0.12	0.48	0.040	0.09
6	3312-Y	1.00	1700	8 16	0.047	0.045	0.040	0.040	0.040	0.46	0.64	0.039	0.08
7	2352-Y	1.75	575	10 20	0.039	0.042	0.040	.....	.....	0.17	0.47	0.040	0.08
8	No. 8	1.75	650	15 10	0.041	0.046	0.041	0.041	.....	0.12	0.47	0.041	0.08

It is interesting to notice that the amount of fluorspar used did not vitally influence the sulphur absorption with the exception of 2 and 8. As a whole, the test does not prove conclusively that sulphur contained in fluorspar necessarily enters the steel bath. There are conditions where it will and again where it will not. The governing factors, of course, are the chemistry and physical conditions surrounding the slag.

The amount of direct desulphurization caused by fluorspar is debatable. The *Iron Age* of March 23, 1922, discusses a German investigation where nine heats of steel produced without fluorspar average 0.08 sulphur; whereas nine heats produced with fluorspar averaged 0.05 per cent sulphur. At present, this seems debatable, because the oxygen of bases in the first instance to the acids was 1.67 as against 1.30 in the second case. But doubtless where the chemistry of slag is in proper proportion for desulphurization the fluorspar aids in quickening the action.

A paper was read before the American Iron and Steel Institute at its fall meeting 1925 by G. H. Jones outlines "Fluorspar and Its Uses." He describes its qualities as, "The demand for steel making is for a washed gravel, sized ¾ inch and under, of 85 per cent and over in calcium fluoride and not to exceed 5 per cent in silica and free from sulphides, lead and zinc." There is no question about such an analysis. The higher the fluoride the more active the flux and the lower the silica the less lime and fluorspar it takes to flux the addition. Fluorspar is principally used to "smooth" out a slag by fluxing the higher temperature compounds already existing in it. It may be of some interest to insert here that a test run with dry and wet fluorspar carrying 8 per cent free water gave the following results:

A quicker action was noticed when the fluorspar was wet with 8 per cent of water. A slight explosion took place with the result that the slag was moved and readily admitted the flux. In the case of the dry fluorspar, when shovelled into the furnace it remained on the top of the slag for some minutes before starting to work. In this experiment the time was in the ratio of 1 to 3.

The fluxes, calcium chloride and sodium fluoride will be discussed under the third part of this paper.

A description of a good slag should carry the following factors:

1. Should have an apperance of a quietly flowing mass of creamy consistency.

2. Should form a thin envelope around a bar which had been thrust into the slag and subsequently withdrawn.

3. Should not effervesce in the test spoon.

4. Should have surface tension enough to hold together and allow the metal in the test spoon to run freely into the mold.

Conclusions

The conclusions to be drawn from the information given on fluxes are:

1. That they shall not materially alter the final relation of acids to bases.

2. That they shall actively lower the freezing point of the slag.

3. That they shall have chemical and physical requirements which permit easy penetration of the slag and do not volatilize and be carried away in the gases of the furnace, to the detriment of the brick work.

4. That they shall not in their proper use produce a slag which will actively cut the banks.

5. That they shall under good conditions be a desulphurizing adjunct.

Fluxes and Desulphurizers

The statement of Benedict Crowell in the Engineering and Mining Journal, January 2, 1922, "It is not generally realized that the known fluorspar deposits of this country are very limited in extent," caused some agitation among investigators to find a substitute for fluorspar. With this thought in mind, the following investigation was performed:

A large steel company permitted Hickman Williams & Company to investigate the possibilities of soda ash (sodium carbonate) as a substitute for fluorspar and as a desulphurizing flux. The test covered 176 heats in all and in which over 26,274,618 pounds of steel were treated.

The object of test was not only to find a substitute for fluorspar but also to widen the application and use of soda ash. As a consequence of this, the Michigan Alkali Company of Wyandotte, Michigan, gave its aid in the preparation of the ash to the requisite physical and chemical structure. The first tests were performed on

Table II

Heat No.	Metal Charged	Amount Pig	Amount Lime	Amount Ore	Amount Flux	Time
1	227,430	67,700	12,300	7,000	300 lbs. Ash	9′25″
Remarks: Slag in good shape and drained easily.						
2	280,504	124,000	21,600	....	700 lbs. Ash	11′25″
Remarks: Slag quiet—in fair shape.						
3	24,900	89,300	14,100	1,500	75 lbs. Ash	9′25″
Remarks: Slag fair—gassy.						
4	250,475	91,600	13,200	....	400 lbs. Ash	12′05″
Remarks: Slag fair—quiet.						
5	226,825	79,800	12,600	....	300 lbs. Ash	11′20″
Remarks: Slag excellent—quiet.						
6	226,479	66,300	13,200	1,000	700 lbs. Ash	10′35″
Remarks: Slag quiet and in good condition.						
7	226,050	70,700	12,400	3,000	297 lbs. Ash	9′30″
Remarks: Slag very liquid, ash acted somewhat like fluorspar; acted rapidly and less amount used than fluorspar.						
8	234,181	76,700	12,000	3,000	50 lbs. Ash	12′20″
Remarks: Condition of slag fair—no fluorspar used.						
9	216,664	69,600	11,800	1,500	25 lbs. Ash	8′20″
Remarks: Ash was used to cut floaters of lime—acted rapidly.						
10	206,454	5,400	13,200	1,000	400 lbs. Ash	8′10″
Remarks: Soda ash worked rapidly, cut up lumps and heat in good shape—no fluorspar used.						
11	250,450	81,700	11,400	1,500	300 lbs. Ash	7′45″
Remarks: No fluorspar used, ash cut up floaters quickly, shaped heat nicely.						
12	253,856	87,800	1,400	1,500	400 lbs. Ash	8′05″
Remarks: Ash acted rapidly and made slag smooth and creamy; no fluorspar used.						
13	296,860	146,300	20,000	....	600 lbs. Ash	11′50″
Remarks: Soda ash used on this heat; did not shape up—could not pull the lime from the bottom—raw lime used—600 lbs. of fluorspar used to finish heat.						
14	273,905	120,900	23,800	....	2,500 lbs. Ash	13′40″
Remarks: 2,500 lbs. soda ash used, would not pull lime from bottom. Had to use 200 lbs. of fluorspar to thin slag. Raw lime used.						
15	26,156	82,100	12,000	1,500	250 lbs. Ash	9′45″
Remarks: 250 lbs. Soda Ash—shaped up slag; no fluorspar used.						
16	228,508	72,900	14,000	....	1,000 lbs. Ash	12′40″
Remarks: Shaped slag up in good condition.						
17	232,710	75,400	13,600	....	850 lbs. Ash	10′38″
Remarks: Slag very liquid—in good condition; pulled sulphur from .054 to .040 with a 30″ delay.						

burned lime heats. Table II indicates the results. No desulphurization in the furnace was attempted in this test.

No slag analyses were run on these first 17 heats. It did not seem to be necessary because whether ore was used or not the soda ash flux worked when burned lime was used. In heats 13 and 14, however, when raw lime was in the charge, soda ash refused to bring the slag to proper shape. Inasmuch as this was the last of the ash available, it was decided that the experiment should be continued and a trial of another lot of soda ash should be used on raw lime heats. It will be noticed from the foregoing data that soda ash has some merit as a flux where burned lime is used.

The amount of ash used compares favorably, on an average, to that of fluorspar even though the ash was used on every heat.

During this experiment ladles of metal were treated with soda

Table III

Heat	Amount	Sulphur	
		Tapping	Final
	Pounds of Soda Ash		
1	225	0.040	0.037
2	400	0.042	0.032
3	150	0.038	0.040
4	250	0.038	0.038
5	300	0.044	0.038
6	500	0.038	0.035

ash to see if any sulphur reduction could be effected. The result is shown in Table III.

The conclusions to be drawn from Table III seem to indicate that sulphur reduction is possible by the use of soda in the ladle Heats 3 and 4 will be immediately produced to show that the operation is unreliable. But in these two instances the ash was placed in the ladle after the heat was completely tapped and slag was on the surface of the ladle. In the other 4 tests, the soda ash was placed in the ladle when about ¼ full of molten steel.

It seems that there is a reaction between the ash and the slag which causes a reversible action to take place, sending the sulphur back to the steel. There is a further deduction which may be drawn and that is the lower the sulphur the greater the amount of ash required to perform equal percentages of sulphur reduction. Another factor which seems to influence ladle sulphur-reduction is that of temperature, i. e.; the higher the temperature the more difficult it is to perform sulphur reduction.

While the desulphurization tests were being performed at the open-hearth, it was suggested that an attempt be made to desulphurize blast furnace iron. Accordingly the next experiment was run:

At the blast furnace: Four ladles of iron were given over to the treatment. Two of these ladles were treated and two untreated.

Amount of Iron Treated	Soda Ash Used	Sulphur	
		Tapping Per Cent	Final Per Cent
20 Tons	None	0.039	0.033
20 Tons	185 pounds	0.039	0.028
17 Tons	None	0.039	0.031
17 Tons	160 pounds	0.039	0.028

Again, desulphurization may be accomplished at the blast furnace, but not in the amount expected. In running such an ex-

periment and untreated ladle should be also given the longest time possible to the untreated and the shortest time reasonable for the treated ladle. All in all, at the conclusion of this test, it was decided that the results warranted continued experiments and so five months later 42,773 pounds of flux were shipped for experimental purposes. The experiment progressed, because the fundamentals seemed apparently correct and added to this the practical demonstration seemed to prove the theory. The work was performed on the chemical and thermal data which follows:

$$(16)\ Na_2CO_3 + SiO_2 = Na_2SiO_3 - CO_2$$

The sodium silicate has a freezing point of 1864 degrees Fahr. (1018 degrees Cent.) as against the calcium silicate of 2753 degrees Fahr. (1512 degrees Cent.) The decomposition of the sodium carbonate takes place in the presence of silica at slightly over 1560 degrees Fahr. (849 degrees Cent.), its melting temperature. Hence, the reaction (16) given seemed probable. The specific gravity of the ash is given as 2.43-2.51 as against the fluorspar 3.15-3.18. This difference was narrowed when the ash was prepared by fusing and other preparation. The desulphurizing equation supposed was:

$$(17)\ Na_2CO_3 + Mn\cdot S + Si = Na_2S + Mn$$

The reaction must take place either in the presence of a well fluxed SiO_2 or in its total absence or reaction (16) will take place with a reversion of sulphur to the molten steel. This explains in a way the sporadic results obtained unless care is exercised in the process. In all the instances where desulphurization was accomplished, the slag did not proportionately raise in sulphides. Therefore, it would seem that there was a volitalization of the sulphide as SO_2. Also, in every case where this desulphurization was obtained there was an increase of manganese in the steel. There are two possibilities for this phenomenon (1) that the sulphur in a well fluxed slag was in the form of manganese sulphide which was broken up in accordance with (17) and the manganese reduced and reverted to the steel; (2) the manganese which is usually lost through desulphurization was saved through the action of the ash on the metal.

A list of the heats performed on the second test are given. A total of 74 heats are shown with remarks due to the various

combinations used in developing a desulphurizer as well as a flux which could be substituted for fluorspar.

It will be noticed that there is a considerable variation in the fluxes used. This was caused by the desire to find a material in proper amount which would aid soda ash in becoming a consistent flux. Further, the metal charges were kept as constant as possible as were the lime amounts. The ore used varied with the type of steel to be made and the working of the furnace. The fuel used was oil and the sizes of the furnaces was 75 and 120 tons.

The size of the furnace did not seem to influence the results. The sharpness of the flame, however, varied the temperature which influenced the viscosity of the slag. It was found that better action resulted in all cases where the flame was sharp.

The pig iron used varied from 1.20 to 1.40 silicon, the manganese, 2.00 to 2.32. No real definite conclusion could be drawn showing that this variation influenced the results. The lime content varied between 8 and 10 per cent of the metal charged. Again, this variation did not consistently interfere with the operation of the flux. There was a variation caused by the use of burned lime as against raw lime. A variation in the ore used seemed to help matters, but still in some cases with large amounts of ore the fluxes used refused to work. The list of heats follows:

Heat No.	Metal Charged Lbs.	Amount Pig Lbs.	Amount Lime Lbs.	Amount Ore Lbs.	Amount Flux Lbs.		Time
1	154,500	86,800	13,500	....	375	Ash	8′20″
Remarks: Made fine looking heat; did not gum any, but was a little lumpy.							
2	165,452	81,500	13,000	....	150	Ash	10′
Remarks: Soda ash worked O. K.							
					400	Ash	
3	159,354	77,700	12,800	500	400	Fluorspar	8′20″
Remarks: Used fluorspar a/c soda ash not able to cut and shape up slag.							
					300	Ash	
4	152,600	70,100	12,700	....	400	Fluorspar	8′35″
Remarks: Had to use fluorspar to shape up heat.							
5	15,891	76,500	13,000	....	375	Ash	11′20″
Remarks: Slag thick and gummy.					75	Fluorspar	
6	160,225	77,900	12,400	1,500	200	Ash	8′35″
Remarks: Heat melted 1.50 carbon, added 200 lbs. soda ash, which cut lime, added 1,500 lbs. ore, which helped to thin slag; slag too heavy to drain from furnace.							
7	149,700	60,900	12,700	....	375	Ash	8′35″
Remarks: Slag heavy, had to get action on bath after ash was added, so fluorspar was added.							
					325	Ash	
8	158,560	63,900	13,000	1,000	400	Fluorspar	9′
Remarks: Had heat to get in shape; slag too heavy and thick—fluorspar opened it up.							
					300	Ash	
9	170,704	83,900	12,600	1,000	100	Fluorspar	9′15″
Remarks: Slag was thinned—shaped up nicely.							
					300	Ash	
10	159,600	77,000	13,000	1,000	100	Fluorspar	9′35″
Remarks: Slag heavy, required fluorspar to open.							
					400	Ash	
11	157,254	70,800	14,000	1,700	75	Fluorspar	8′30″
Remarks: 5 shovels of fluorspar mixed with 400 pounds soda ash; slag shaped up with nice action—soft and creamy.							

Heat No.	Metal Charged Lbs.	Amount Pig Lbs.	Amount Lime Lbs.	Amount Ore Lbs.	Amount Flux Lbs.	Time
12	168,650	80,300	13,000	3,500	50 Fluorspar	9′55″
Remarks: Soda ash mixed with fluorspar; slag shaped up nicely; fine action.						
13	166,850	83,900	13,500	1,500	200 Ash	10′05″
Remarks: Soda ash put slag in good shape.						
14	148,250	56,200	13,400	500	150 Ash	8′30″
Remarks: Slag very thin—soda ash thickened but would not hold it.						
15	157,551	42,900	13,500	500	800 Ash	9′20″
Remarks: 400 pounds soda ash charged with limestone—400 pounds added to slag—slag thin —fine shape.						
16	157,750	74,100	13,400	1,000	350 Ash	8′55″
Remarks: Slag good.						
					330 Ash	
17	155,800	75,500	13,100	....	100 Fluorspar	10′10″
Remarks: Ash would not thin slag—fluorspar cut rapidly.						
					400 Ash	
18	151,300	69,700	13,000	....	30 Fluorspar	7′50″
Remarks: Mixture shaped slag nicely.						
19	155,252	69,600	13,600	....	400 Ash	10′
					400 Ash	
Remarks: Soda ash worked nicely.						
20	158,000	74,400	12,800	1,000	100 Fluorspar	9′20″
Remarks: Combination shaped up slag nicely.						
21	152,302	58,600	12,900	....	...	12′45″
Remarks: No flux used.						
					400 Ash	
22	159,002	74,300	13,100	....	150 Fluorspar	10′20″
Remarks: Combination shaped slag nicely.						
23	177,350	90,100	12,800	500	400 Ash	9′15″
Remarks: Soda ash cut slag nicely.						
					400 Ash	
24	156,352	55,200	13,400	1,000	150 Fluorspar	9′35″
Remarks: Spar required to open up the slag.						
25	155,852	72,600	13,800	....	200 Ash	11′50″
Remarks: Soda ash thinned slag.						
					215 Ash	
26	151,777	80,700	12,700	....	175 Fluorspar	9′25″
Remarks: 20 pounds silica sand mixed with combination worked nicely.						
					400 Ash	
27	159,202	51,400	12,900	1,500	32 Fluorspar	9′
Remarks: 400 pounds soda ash—32 pounds fluorspar mixed added to furnace and worked nicely.						
					400 Ash	
28	159,010	77,300	12,700	1,000	45 Fluorspar	9′50″
Remarks: Slag heavy until spar and ore were added. Slag thinned up quickly.						
29	146,602	73,000	13,000	....	600 Ash	9′35″
Remarks: Heat melted 0.40 carbon—slag heavy. Added 100 pounds soda ash 1.15 slag heavy 100 pounds soda ash 12.25 slag O. K. Slag test at 1.30 metal extra hot air off 1.30. 200 pounds of manganese at 1.45 oil off 1.50 tapped at 1.55. No ore used. Slag in good shape.						
					400 Ash	
30	158,204	74,500	12,700	....	50 Fluorspar	8′50″
Remarks: Mixture gave good slag.						
31	156,954	73,200	12,500	....	400 Ash	
					250 Fluorspar	9′
Remarks: Mixture 400 pounds soda ash and 50 pounds fluorspar would not work—added 200 pounds fluorspar.						
					325 Ash	
32	157,385	73,500	13,400	200	400 Fluorspar	7′35″
Remarks: 17½ per cent mill scale mixed with 325 pounds soda ash would not work. Required 400 pounds fluorspar to open slag.						
					No Ash	
33	164,800	77,300	12,400	2,000	50 Caustic Soda	12′30″
Remarks: Slag thinned rapidly, then thickened—became stringy while tapping.						
					400 Ash	
34	149,200	48,100	13,700	....	50 Fluorspar	7′35″
Remarks: Soda ash and fluorspar mixed; slag thinned rapidly.						
35	158,302	75,400	12,600	....	800 Ash	9′50″
Remarks: 400 pounds ash used in furnace—thinned slag; 400 pounds in ladle. No sulphur reduction.						
					400 Ash	
36	155,802	55,800	12,700	....	32 Fluorspar	11′10″
Remarks: Fluorspar required to open slag.						
					300 Ash	
37	150,908	52,400	13,500	1,500	50 Fluorspar	9′00″

Heat No.	Metal Charged Lbs.	Amount Pig Lbs.	Amount Lime Lbs.	Amount Ore Lbs.	Amount Flux Lbs.	Time
Remarks: 50 pounds fluorspar required to shape slag.						
38	166,750	79,300	14,900	1,500	100 Fluorspar 400 Ash	9′25″
Remarks: Fluorspar required to shape slag.						
39	156,418	80,300	13,500	....	470 Ash 150 Fluorspar	9′25″
Remarks: Mixture shaped slag quickly.						
40	155,450	73,200	13,600	500	400 Ash 100 Fluorspar	9′05″
Remarks: 100 pounds fluorspar required to shape slag.						
41	158,734	74,600	13,000	....	150 Ash 150 Fluorspar	11′20″
Remarks: Mixture gave good slag.						
42	152,802	69,600	12,900	1,000	400 Ash 150 Fluorspar	9′40″
Remarks: 150 pounds fluorspar required to shape slag.						
43	156,550	48,000	13,300	1,000	400 Ash 50 Fluorspar	9′55″
Remarks: Slag thick—50 pounds fluorspar added—thinned rapidly.						
44	156,402	77,400	12,200	....	150 Ash	9′40″
Remarks: Soda ash worked rapidly on slag.						
45	159,630	76,500	13,300	....	400 Ash 100 Fluorspar	9′20″
Remarks: Fluorspar required to thin slag.						
46	161,209	73,800	13,400	....	300 Ash 300 Fluorspar	8′50″
Remarks: Slag thick until fluorspar was added.						
47	152,710	72,000	13,000	....	400 Ash	10′20″
Remarks: Slag thin, 1,000 pounds burnt lime added to thicken.						
48	160,022	51,900	13,300	....	400 Ash 200 Fluorspar	9′
Remarks: Slag thick—fluorspar thinned it rapidly.						
49	163,102	75,600	12,000	1,500	400 Ash 75 Fluorspar	9′25″
Remarks: Slag heavy; fluorspar shaped it up.						
50	145,454	68,500	12,600	1,000	400 Ash	8′15″
Remarks: Slag heavy—ore thinned it up.						
51	156,665	75,400	13,700	....	400 Ash 100 Fluorspar	10′15″
Remarks: Slag thick--fluorspar thinned it.						
52	156,164	74,000	14,500	300	400 Ash 100 Fluorspar	10′20″
Remarks: Same as 51.						
53	163,010	80,100	14,200	....	400 Ash 400 Fluorspar	8′30″
Remarks: Same as 51.						
54	141,566	79,700	13,100	....	50 Caustic Soda	11′05″
Remarks: Caustic cut rapidly—slag gummed.						
55	160,706	54,800	12,000	1,000	200 Ash 150 Fluorspar	9′
Remarks: Same as Heat 51.						
56	161,307	62,000	12,300	2,000	125 Ash	9′10″
Remarks: Ash shaped slag after ore was used.						
57	161,210	78,700	12,900	....	200 Ash 200 Fluorspar	8′05″
Remarks: Same as Heat 51.						
58	153,100	46,800	13,400	....	400 Ash 90 Fluorspar	8′40″
Remarks: Same as Heat 51.						
59	159,100	82,100	13,800	....	400 Ash 200 Fluorspar	9′30″
Remarks: Same as Heat 51.						
60	159,500	80,300	12,500	2,000	400 Ash	9′05″
Remarks: Ash cut lime quickly.						
61	148,320	69,300	12,400	....	300 Ash 100 Fluorspar	11′00″
Remarks: Same as Heat 51.						
62	155,723	78,900	14,400	....	200 Ash 200 Fluorspar	10′00″
Remarks: Same as Heat 51.						
63	171,171	74,700	12,800	....	300 Ash	9′05″
Remarks: Soda ash cut lime quickly.						
64	144,818	69,400	12,000	....	200 Ash 50 Fluorspar	7′55″

Heat No.	Metal Charged Lbs.	Amount Pig Lbs.	Amount Lime Lbs.	Amount Ore Lbs.	Amount Flux Lbs.	Time
Remarks: Same as Heat 51.						
65	150,558	72,400	12,800	1,000	400 Ash 200 Fluorspar	9'40"
Remarks: Same as Heat 51.						
66	157,510	44,200	12,800	....	400 Ash 300 Fluorspar	11'30"
Remarks: Same as Heat 51.						
67	146,504	78,800	12,000	....	150 Ash	10'20"
Remarks: Slag was in good shape—soda ash acted rapidly.						
68	154,000	55,700	14,200	3,000	175 Ash	10'15"
Remarks: Slag shaped up fine.						
69	150,511	63,700	14,200	2,000	75 Rock Salt	10'00"
Remarks: Rock salt cut slag in good shape.						
70	152,800	73,000	13,700	....	250 Ash 100 Rock Salt	9'55"
Remarks: Combination put slag in good shape.						
71	145,900	50,800	14,000	3,000	200 Ash 100 Rock Salt	7'55"
Remarks: Combination put slag in good shape.						
72	164,402	70,600	13,500	2,000	200 Ash 100 Rock Salt	11'15"
Remarks: Combination put slag in very good shape.						
73	151,850	64,500	13,600	500	60 Rock Salt	9'10"
Remarks: Salt cut up slag very quick and good.						
74	154,252	72,000	14,200	1,000	100 Ash 100 Rock Salt	9'30"
Remarks: Mixture cut slag very quickly.						

If we consider the first four heats, a general idea of the inconsistant action of soda ash will be seen. The lime used was in the raw state. The first two heats worked entirely on ash whereas the second two refused to take proper action until fluorspar was introduced. When the ash was added, it cut up the "lumps" readily in all cases. Then, as the heats progressed the slag either took a good fluidity or became thick. This thickness restricted the action and fluorspar had to be used to open the slag. To parallel this thickness, it might be said to appear like a blanket slag caused by chromium. The instant that the fluorspar came into contact with this heavy slag, reaction immediately started and the slag took its proper consistency.

There does not appear to be any great variation between these four heats or between this set and those run on burnt lime. Yet the proportion of all the heats worked with soda ash appears to be in approximately the proportion of 50 per cent working successfully and 50 per cent requiring other fluxes to finish the slag. The amount of fluorspar required to open up the various slags did not remain constant. Hence, there was in all probability a variation in the chemistry of the slags. To this end, slag analyses were made on all heats before any outside flux was used to aid the ash.

The following is a table of the results with the remarks:

Condition of Slag	Heat	Ferrous Oxide	Ferric Oxide
Thick	5	14.41	6.74
Good-Heavy	6	10.29	1.92
Dead Heavy	7	10.55	8.00
Thick	8	9.14	5.82
Good	1	11.06	6.00
Good	2	9.26	3.68
Good	9	13.57	.94
Good	12	12.29	2.50
Thick	10	12.74	4.01
Good	11	10.94	2.84
Good	13	16.47	2.19
		13.25	...

The viscosity of these slags seems to be controlled somewhat by total percentage of FeO plus Fe_2O_3 present and by relation of FeO to Fe_2O_3. When the totals are low, the slag seems to be thin and active—where the totals are high, and Fe_2O_3 low, slag seems to be still active. But where totals are high, and Fe_2O_3 is high, slag becomes mucky. There were other variations in the slag analyses but nothing was evidenced which would cause the slag to vary in viscosity as it did in these tests.

It seems as though the state of oxidation of the iron in the slag restricts the reaction of the soda ash which could be normally expected. It would be almost possible to conclude that the ash after decomposition was not allowed to attack the SiO_2 in the presence of the iron oxides. Consequently it was not fluxed and the balance of acids to bases was disturbed with the result that Na_2O, a very strong base, thickened the slag.

As the lists of heats are scanned, it becomes evident that the action of ash in the open-hearth was sporadic, and that under similar conditions, it acts differently. Just when it should act, it works to the contrary, and when least expected to perform, it accomplished the purpose aimed for. In many cases fluorspar had to be added to the slag after the ash. The ash seemed to work up to a point, and then lose its activity. It seemed to cut into the lumps with ease and smooth them out nicely, but as soon as this action had been completed, the slag began to grow gummy and act almost as dough, when it is kneaded. But in cases where quantities of ore, say over two or three thousand pounds were used, the ash seemed to perform its function nicely.

But, in many cases where ore had been used, in all probabilities, no ash or fluorspar would have been required, because the silica

in the ore and the boiling action caused by the introduction of the ore into the bath of steel, usually thinned up the slag proportionally to the amount of ore added. Further, the ash seemed to work in good shape in heats which had melted high in carbon. It also worked where pig iron was introduced after the introduction of the ash. But, on the whole, the ash seemed to thicken the slag when the "heat" was passing through the range of 0.35 to 0.50 per cent carbon, and at this point after no ore or pig iron was introduced, the slag started to gum up and increase in its viscosity relatively to the time in the furnace.

Heats 51 to 66, excepting 54, were used to determine reaction of fluorspar and ash. When the fluorspar was introduced, a violent reaction took place. The fluorspar seemed to go to work immediately, and the slag thinned out with very small amounts of fluorspar being added. The reaction of fluorspar with soda ash was plainly visible when compared to a straight fluorspar heat. There seemed to be some affinity of one of the elements in the soda ash for one of the elements in the fluorspar. This affinity was believed to be an interchange of the fluorine in the fluorspar with the sodium in the soda ash. And it was felt that sodium fluoride was formed. To check this assumption, salt and fluorspar were introduced, adding the salt first, and then introducing the fluorspar later. Similar violent reaction to the soda ash and fluorspar combination took place.

It will be noticed that salt and soda ash became a prevalent combination. It was believed that soda ash alone would never do, and it became the policy to find some element or compound to mix with the soda ash in order that it would function properly as a flux. It was felt that after a trial with salt, had discovered the ingredient, which would permit the use of soda ash as a substitute for fluorspar. Heats 69 to 74 inclusive were used in the salt tests.

During the following week, we continued to experiment to find the proper percentages of the combination of salt and soda ash, and finally determined that a fifty-fifty mixture would be the ideal combination. This flux seemed to work out nicely every time it was used.

The objection to the salt, however, was that it gave out great volumes of smoke, which condensed on the sides of the furnace and also went into the "checkers". This, of course, was objectionable.

It was first thought that when the soda ash and salt were fused together, this smoky feature would be overcome, but it was later proven that the volatilizing of the salt took place, and such being the case, salt would never be of any value to us in compounding a flux. It was therefore thrown into discard later, and new combinations were sought.

During the course of work, we tried out mill scale mixed with soda ash (Heat 32). We also tried silica sand and mixed with ash (Heat 26). In one instance, glass was tried out, but none of these combinations worked with the high activity of soda ash and fluorspar, and it became evident that we must find a material which would blend with this slag, giving the characteristics of the soda ash and fluorspar mixture. During this investigation, we obtained some caustic soda (Heat 54). We tried this out in the furnace. The slag was unsatisfactory, due to it becoming gummy and sticky. After the slag had shaped up, it seemed as though the caustic volatilized and the slag thickened. This bad feature of the caustic volatilization caused an irritation on the skin of the melters and therefore was discarded.

It may be safely said that a mixture of soda ash and fluorspar gives a better slag than fluorspar alone. It may be also said that soda ash alone is too erratic and too many variables affect it to make it valuable as a flux alone. It may be further stated that soda ash has some merit as a desulphurizer in the ladle, as shown by the ladle tests in section number 1, as well as section number 2.

After considerable success with sodium chloride and ash, difficulties were experienced and a complete log was carried on two heats. This data is given—

Report of Heats using 50% Soda Ash and 50% Rock Salt

Heat No. "X"	Time of Additions	Additions and Amount	Remarks on Slag and Other Conditions
	10:40A	Salt 10 shovels	Melted about 30 carbon—slag lumpy and very heavy.
	11:05A	10 shovels	No action on lumps—still heavy.
	11:25A	10 shovels	Slag viscous—still lumpy.
	11:35A	(10 shovels) (Fluorspar)	Open slightly—slag viscous and very heavy
	11:45A	(10 shovels) (Fluorspar)	Not much change—slag opened some.
	12:00N	Recarb	No action when recarb was poured. Tapped 12:05P, slag was very heavy and viscous. Left bottom dirty.

			Delay of 40 minutes getting heat in shape.
"Y"		Salt	
	10:30A	10 shovels	Melted about 70 carbon—Slag lumpy and very heavy.
	10:50A	10 shovels	Not much change on slag—still heavy.
	10:55A	1000 #ore	Ore opened up slag a little.
	11:35A	10 shovels	Rods were used—slag opened up some. Still heavy and viscous.
	11:45A	spar 24 shovels	Opened up and action on slag.
	12:15P		Slag thickened and lay flat—boiling #1 door.
			No recarb—tapped 12:25P slag heavy and viscous—left bottom dirty, delayed one hour getting heat in shape.

These heats consisted of making forging bar steel and were 271403 lbs.—280706 lbs.—237604 lbs. respectively. The lime varied from 9% to 9.8% respectively. The amount of flux used, varied from 300 lbs. of the salt and soda mixture, plus 300 lbs. of fluorspar to 600 lbs. of salt and soda with no fluorspar, and 210 of salt and soda with 360 lbs. of fluorspar. The final remarks will be noticed, and from this time on, we began to experiment with other materials.

During one run on heat "A" and heat "B", slag analyses taken to see if all of the salt was volatilizing, or whether some of this material remained in the slag. These determinations were performed upon slags which were taken periodically from the slag volume in the furnace, and it will be noticed that a large proportion of the fluorspar remains in the slag, and that further, some proportion of the salt remains in heat "B". The following are the determinations:

Heat	SiO_2	FeO	Fe_2O_3	CaO	Fluorspar CaF_2		
"A"							
	22.12	11.32	3.16	39.70			Before ore was added.
	18.84	12.86	5.46	40.10			After ore added—Before
	16.40	7.98	9.90	45.70	.84		15 min. after fluorspar
"B"	15.66	9.00	8.89	46.10	.97		Before additions
	19.48	11.58	5.60	39.60			Before ore was added.
	17.72	13.25	7.60	39.10			After ore was added.
	16.72	13.51	8.17	40.80	.50	NaCl	
					.49		15 minutes after salt added.
	16.00	10.55	8.45	44.00	.62	.58	Before additions

As soon as it was found that the salt was volatilizing, and

would not do as an adjunct to the fluorspar, an investigation of the mixture of calcium chloride and soda ash was started, but inasmuch as it was later found that the calcium chloride worked only similarly to fluorspar and cost more, this product was discarded. Sodium sulphate was the next compound to be mixed with soda ash, but this combination did not give the desired results. Therefore this compound was eliminated from further consideration. Borax was the next compound to be used, and this acted very similar to sodium sulphate and was given no further consideration.

All during these heats, it became more and more evident that sodium fluoride was the proper compound to use in finding a substitute for fluorspar. Consequently it was tried out on one heat, which supposedly carried a very difficult slag to work. When the sodium fluoride was added to the furnace, there was no doubt left but that the proper material had been found. Following up this result, several heats were worked with this material which checked the first results, and it became evident that this compound would work under all conditions.

The following list of heats will give an idea of the work performed and the varying compositions of fluxes used:

Heat No.	Metal Charged Lbs.	Amount Pig Lbs.	Amount Lime Lbs.	Amount Ore Lbs.	Amount Flux Lbs.	Time
1	271,403	87,000	24,500	....	300 Mix 300 Fluorspar	11′15″
Remarks: 50-50 soda and salt mixture cut lumps, but did not thin slag. Fluorspar had to be used.						
2	280,706	93,100	23,000	....	600 Mix	13′20″
Remarks: 50-50 salt and soda put slag in fine shape.						
					210 Mix	
3	237,604	124,600	23,300	1,000	360 Fluorspar	13′15″
Remarks: 50-50 salt and soda mix cut slag but then it grew heavy—finished with fluorspar.						
					780 Rock Salt	
4	264,922	121,700	28,800	....	400 Fluorspar	11′05″
Remarks: Salt acted slowly—fluorspar added and acted rapidly.						
					350 Rock Salt	
5	263,200	140,900	26,000	4,400	175 Fluorspar	11′20″
Remarks: When fluorspar was added reaction was *violent*—slag thinned.						
6	221,000	111,100	26,100	1,000	500 Fluorspar	10′30″
Remarks: Slag creamy and thin—Compare Heat 18,842.						
					200 Fluorspar	
7	260,353	96,000	25,000	500	165 Fluorspar	11′40″
Remarks: 360 pounds flux used—put slag in good shape when 165 pounds fluorspar was added.						
					240 Table Salt	
8	231,964	112,100	25,000	....	150 Fluorspar	11′45″
Remarks: Table salt acted better than rock salt—fluorspar added to shape slag.						
9	238,975	103,500	24,600	....	340 Rock Salt 175 Ash 100 $CaCl_2$	10′20″
Remarks: Rock salt and $CaCl_2$ added to furnace—thinned slag. Soda ash added to ladle—thickened slag.						
					400 Rock Salt	
10	237,910	117,900	24,900	1,000	900 Fluorspar	11′25″
Remarks: Slag heavy. Fluorspar used but did not cut slag.						

Heat No.	Metal Charged Lbs.	Amount Pig Lbs.	Amount Lime Lbs.	Amount Ore Lbs.	Amount Flux Lbs.	Time
					550 Rock Salt	
11	305,100	174,100	24,600	....	60 $CaCl_2$	11'40"
					250 Fluorspar	
Remarks: Check heat 24,648.						
					300 $CaCl_2$	11'
12	247,850	136,600	25,300	3,000	650 Fluorspar	
Remarks: Slag in good shape—fluorspar and $CaCl_2$ about equal in strength.						
13	249,800	110,000	20,200	4,000	150NaF	8'20"
Remarks: NaF put slag in better condition than fluorspar.						
14	238,200	134,000	25,400	....	200 NaF	8'40"
Remarks: Best flux yet used. Slag exceptionally fine.						
15	266,330	107,500	22,500	3,000	250 NaF	10'05"
Remarks: Slag heavy NaF cut quickly—reduced sulphur 0.037 to 0.026.						
16	227,514	96,000	22,400	4,000	225 NaF	8'10"
Remarks: Flux cut slag up quickly—dropped sulphur 0.038 to 0.026.						
17	253,150	103,000	25,300	....	400 NaF	8'20"
Remarks: NaF acted rapidly, put slag in fine shape—dropped sulphur from 0.042 to 0.030.						
					400 Rock Salt	
18	239,630	137,600	27,400	....	800 Fluorspar	9'35"
Remarks: Fluorspar added to thin slag. Sulphur Test Heat.						
19	206,076	87,900	24,900	10,000	400 Ash	10'30"
Remarks: Soda ash cut lumps and ore thinned slag. Sulphur Test Heat.						

As the sodium fluoride heats were worked it became evident that a quicker reaction in the loss of carbon and sulphur occurred than was usually expected. Consequently, the bath analysis was taken at definite intervals. The results of these tests are shown in the graphs which are appended. These charts indicate that the most effective flux used was that of the fluoride of sodium. This material seemed to put the slag in a condition which would permit desulphurization and decarbonization readily. In all instances the slags were creamy and quiet, yet very fluid. Less amounts of this flux were used than any other.

The complex reaction which occurs is similar to those expressed for fluorspar. The material is practically insoluble in water and has a specific gravity of 2.766. Its melting point is 1796 degrees Fahr. (980 degrees Cent.) and when used in a slag in the presence of SiO_2 forms sodium silicate whose melting temperature is 1864 degrees Fahr. (1018 degrees Cent.), over (300 degrees Cent.) lower than calcium silicate. The desulphurization is perhaps a function of the flux and then it may be the result of the nature of the slag formed. The charts are self explanatory and the results are obvious.

A resumé will be given in the following substance to facilitate anyone interested, in seeing just exactly what work was performed, and what fluxes were used in the production of the report given in the previous three sections.

Fourteen different combinations were used and the following

chart will show the number of heats which worked and which did not work in this experiment. It will be of further interest to know that 21,274,618 pounds of metal were treated during this test. This amount of metal is taken from those heats which were recorded, and that well over 5,000,000 pounds of additional metal was experimented with before the starting of the recording of the experiments. Out of this 21,000,000 pounds there was 8,792,400 pounds of pig iron; the remainder was scrap. Percentage of pig iron to the total metal, is equal to about 41.3 per cent. During this run, the amount of lime used, was 1,706,200 pounds, which is equal to about 8 per cent of the total metal treated. The amount of ore used, was 101,100 pounds, which is equal to about ½ of 1 per cent of the total metal charged. The following is a list of the heats worked by the various kinds of fluxes.

HEATS

Fluorspar	Not worked	Worked
	0	16
Fluorspar and ash	1	46
Ash	33	38
Salt	1	5
Salt and Ash	11	14
Calcium chloride and fluorspar	0	3
Sodium fluoride	0	5
Caustic soda	0	2
Fluorspar ash and mill scale	0	1
Fluorspar ash and silica	0	1
Salt, ash and fluorspar	0	3
Salt and fluorspar	0	6
Salt, ash, calcium chloride	0	1
Fluorspar and glass	0	1

There are shown on the above chart 176 heats; forty-five of which are listed under the heading "Not-worked". These forty-five heats were worked after fluorspar had been added to the slag. Therefore, in all 131 heats were actually recorded and investigated during this experiment.

The various amount of fluxes as shown in the following table, which gives as a total amount of flux used 54,776, shows that with the 10,632 tons of steel made, we averaged slightly over 5 pounds of flux to the ton of steel produced. It must be remembered that in considering this figure, we did not include any heats that were made where no flux was used. The usual way of striking an average for the amount of flux per ton to the steel produced, is to take the heats over a long period and divide the tonnage of flux

used by the total production. By this method, usually up to 25 per cent of the heats included, have not had any flux used, therefore our figure perhaps will be high. The following is the list of fluxes:

FLUXES—AMOUNTS

Salt	5255
Sodium Sulphate	100
Borax	75
Silica	75
Sodium Fluoride	1225
Calcium Chloride	710
Glass	140
Fluorspar	15529
Soda Ash	31667

Total Amount of Fluxes 54776 Pounds

In drawing conclusions from the above data regarding desulphurization, it becomes important to refer to the work of Nead and Herty. The variables shown in their work influence the disposal of sulphur and perhaps lend an explanation for some of the high sulphur heats produced. Their information undoubtedly applies to other fuels as well.

Nead in his paper "Absorption of Sulphur from Producer Gas in Open-hearth Furnaces" *Transactions,* A. I. M. M. E., Vol. LXX 1924 has shown that if a gas high in sulphur is used, the metal and slag will absorb sulphur. Working with a coal with 0.75 per cent sulphur, his conclusions are:

1. Large quantities of sulphur, possibly up to 0.025 per cent or more, are absorbed from the producer gas by the charge in the open-hearth furnace during the melting-down stage; this is in addition to the sulphur already contained in the metal charged.

2. This sulphur absorption imposes a greater burden of desulphurization on the slag than would exist if a lower sulphur fuel were used.

Herty's experiments at Lackawanna, *Transactions* A. I. M. M. E. Vol. LXXI 1925, confirm Nead's investigations. Some of Herty's conclusions are (They are taken from his paper "Some Factors affecting the Elimination of Sulphur in the Basic Open-hearth Process)":

1. A direct ratio exists between the concentration of sulphur dioxide over the bath and the amount of sulphur picked up by the scrap during melting.

2. A direct ratio also exists between the concentration of sulphur dioxide over the bath and the concentration of sulphur in a

slag containing lime, when sufficient time has been allowed for equilibrium to be established.

3. The use of a gas free from sulphur will allow a much higher percentage of sulphur in the charge of an open-hearth furnace.

4. The use of gas free from sulphur will prevent the loss of time due to high-sulphur heats encountered in present operation.

5. Sulphur-free gas will be economical under certain conditions as it will allow a higher sulphur and, therefore, cheaper pig iron to be used and as there will be no time lost on high-sulphur heats.

6. The economy in using sulphur-free coke-oven gas is much greater than in using sulphur-free producer gas, on account of the larger volumes of producer gas which must be used.

7. Clean coke-oven gas is economical under almost all conditions. The exceptions are when low sulphur charges are in use and when the time lost on high sulphur heats is very small, using these low sulphur charges.

8. When burning any fuel in the open-hearth, the waste gases should not exceed 0.035 per cent sulphur dioxide if sulphur absorption is to be avoided. When coke-oven gas and tar are burned together, the coke-oven gas should be cleaned to 125-135 grains of sulphur per 100 cubic feet of gas if high sulphur heats are to be avoided. If very large amounts of tar are used, 30 gallons per ton of steel, with the coke-oven gas, the sulphur content of the latter may be raised to approximately 150 grains.

The conclusion of all of this subject matter may be drawn from those statements surrounding the chemistry of the slag and the fluxes used to dissolve the refractory compounds. The fluxes used have definite lines which divide them into the classes which produce (1) Proper slags; (2) Proper slags combined with an efficient desulphurization and (3) Improper slags. The entire object of this paper has been realized when the data given on slags and fluxes has been turned over for the use of future investigators to prevent a repetition of constructive effort.

The author wishes to express his thanks to the Inland Steel Company, the Michigan Alkali Company, Hickman, Williams and Company and the Aluminum Company of America for their kind aid in producing the data contained herein. Recognition of the efforts of W. E. Maxwell, Jr. and H. B. Hubbard of Indiana

Harbor, Charles L. Kinney, Jr. of South Chicago, and Fred Lutts of Detroit is gratefully acknowledged.

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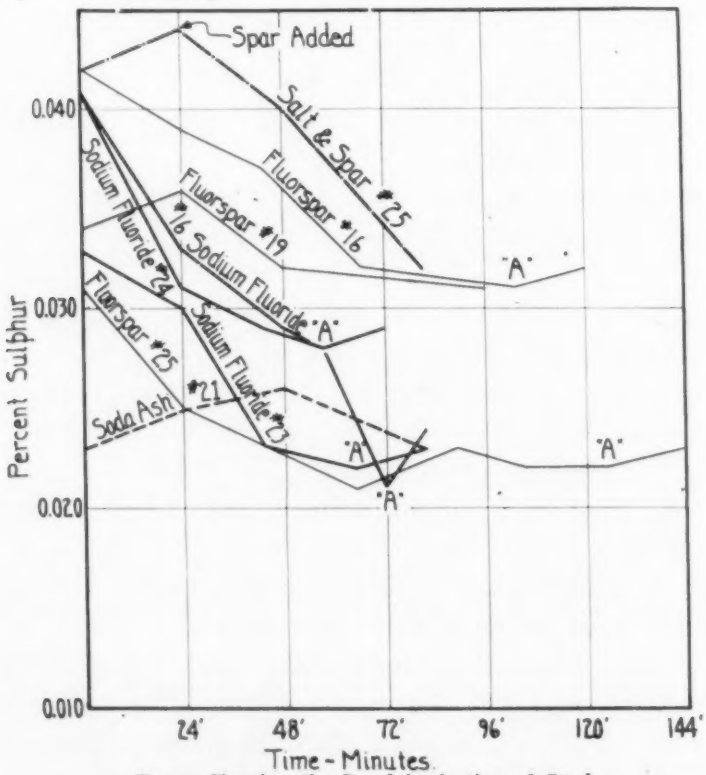
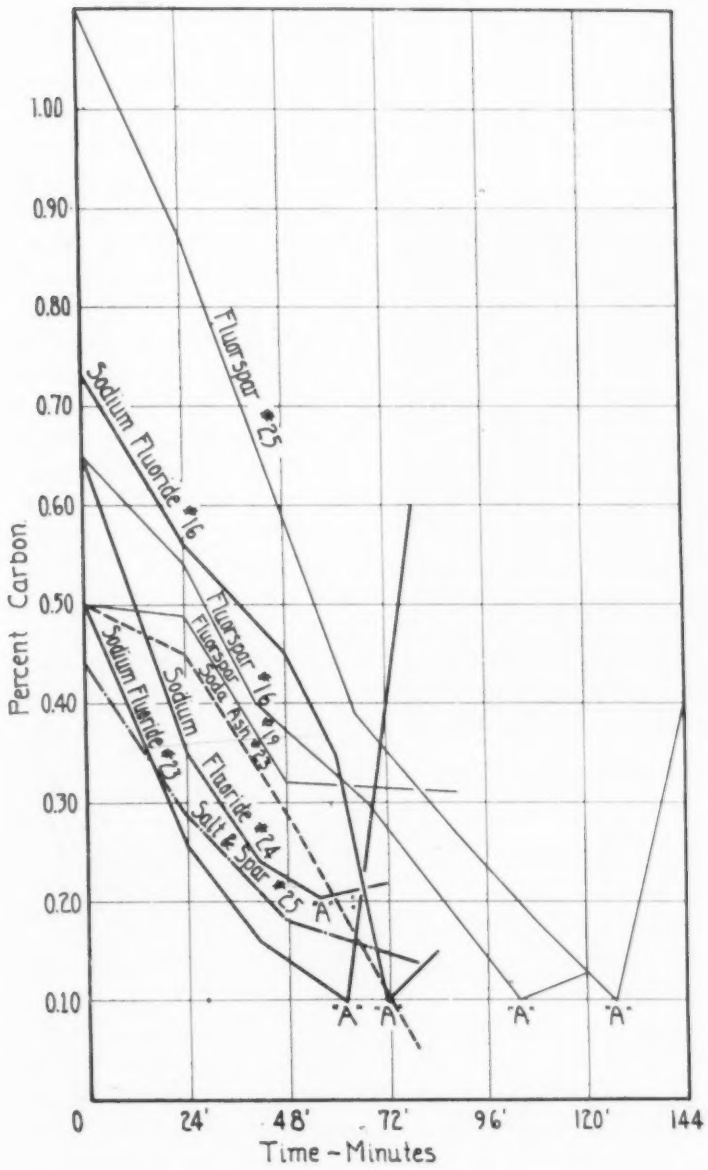


Curves Showing the Desulphurization of Steel
100-Ton Open-Hearth Furnaces
Tests Taken from Bath After Flux was Added.
"A" = Additions—either Alloys or Hot Metal for Re-Carburization.

Legend:—

Furnace No.	Flux	Pounds Per Heat
25	Fluorspar	700
16	Fluorspar	800
19	Fluorspar	800
24	Sodium Fluoride	225
16	Sodium Fluoride	250
23	Sodium Fluoride	150
21	Soda Ash	400
25	Salt	400
	Fluorspar	800



Curves Showing Decarburization of Steel
100-Ton Open-Hearth Furnaces
Tests Taken from Bath After Flux was Added.
"A" = Additions—either Alloys or Hot Metal for Re-Carburization.
Legend:—

Furnace No.	Flux	Pounds Per Heat	Weight of Charge, Pounds	Amount Ore, Pounds
25	Fluorspar	700	262,925	1,500
16	Fluorspar	800	253,600	2,500
19	Fluorspar	800	274,150	2,000
24	Sodium Fluoride	225	253,150	....
16	Sodium Fluoride	250	256,200	....
23	Sodium Fluoride	150	249,800	4,000
21	Soda Ash	400	206,076	10,000
25	{ Salt	400 {	239,630	....
	{ Fluorspar	800 }		

The Author

Since leaving college Mr. Lowry has had varied experience in iron and steel. He has been in the employ of the Watertown Arsenal as foundry foreman, the United States Cartridge Company in charge of steel and heat treating research, the Oliver Chilled Plow Works as chief chemist and metallurgist and supervising melting and heat treating and is now with Hickman, Williams Company in the capacity of metallurgist. In this position, he travels over the whole country consulting with their clients on iron and steel manufacturing problems. He is a member of the American Institute of Mining and Metallurgical Engineers, the American Society for Steel Treating, the American Foundrymen's Association, serving on a number of their committees. He has delivered papers before the most important iron and steel groups and has contributed to various magazines. Recently he was elected to the vice chairmanship of the A-3 committee of the American Society for Testing Materials.

E. J. LOWRY

DISCUSSION

Dr. C. H. Herty, Jr.: I do not believe that one can make a study of fluxes in open-hearth slags without taking into account the entire slag composition. I know that in a great many cases the fluorspar or soda ash, either one, act in entirely different ways, depending on the composition of the slag, the manganese content, the silica content, etc. The first question is on page 911, the ratio of silica to phosphorus in the slag and its variation with the per cent iron in the slag, and also the second part of the table, where the ratio of bases to acids varies with the iron in the slag.

I have calculated some of these ratios from data that I have, and I find with my variation in iron from 20 per cent down to 6.5 per cent, that neither of these two ratios hold at all, no regular variation of the factors given in the table. The data are given below and are taken from a paper on "Chemical Epilibrium . . . . in the Basic Open-Hearth Process", American Institute of Mining and Metallurgical Engineers, February, 1926.

Heat No.	Iron in Slag	SiO_2 / P_2O_5	$CaO + MgO$ / $SiO_2 + P_2O_5$
R	20.67	6.51	3.91
H	16.44	8.10	2.77
N	14.60	6.96	3.40
C	13.86	7.48	2.26
B	13.15	5.95	3.02
M	13.09	8.51	2.82
G	12.40	8.14	2.36
A	10.86	4.27	2.75
K	10.24	10.40	3.56
J	9.72	7.08	3.98
P	9.36	11.15	2.38
Q	9.16	10.86	2.57
S	8.88	7.04	2.58
L	6.46	9.85	2.57

All slag components expressed as weight per cent.

The second point is on page 911, where Mr. Lowry states that "the sulphur reduction is a function of the reactions of manganese which is restricted by the iron oxide present in the slag." I think that statement is possibly correct in itself, but there are a good many other factors which one must take into account to combine with that, the viscosity of the slag and basicity of the slag are just as important as this, although this is probably one of the factors that affects sulphur removal.

The third point is where Mr. Lowry discusses the fluidity of the slags on page 914, second paragraph, in which he states that "Another feature which influences fluidity is the ever changing amount of P_2O_5. There is no accurate data on the freezing points of this acid combined with CaO but it is certain that it produces a fluid melt. There is a relation of P_2O_5 to SiO_2 which governs, i. e.; the lower the SiO_2 the higher the P_2O_5. Hence, a changing fluidity and these causes show why the results are so varying in slag production."

It seems to me that there is no definite relationship between silica and P_2O_5 because the relative amounts depend entirely on the amounts of phosphorus and silicon in the charge. If you have a high silica slag you have more phosphorus in your metal, but that does not necessarily mean that the higher the silica in the slag the less the phosphorus in the slag. You can have almost any silica with any phosphorus up to the amounts you put in, for the simple reason that the phosphorus in the metal is small compared to the phosphorus in the slag and the amount of variation is neglible compared to the phosphorus in the slag.

In regard to the use of soda ash in the ladle on page 919, we tried the same thing Mr. Lowry did, on putting soda ash into the ladle, and on the heats tested we found no reduction in sulphur by the use of 200 pounds of soda ash in a 100-ton heat. The sulphur was just the same in the finished steel as it was in the tapping test.

In the soda ash used in blast furnace ladles, there is one factor which I do not believe Mr. Lowry has taken into consideration, that is, the effect of manganese on the desulphurization action of iron. You cannot put soda ash into a high manganese ladle and get desulphurization and attribute it as desulphurization due to soda ash, when you know that high manganese iron will desulphurize, and I think you specify the manganese as being the same in all these. You probably attribute this to the soda ash, but you have in that case another factor, which is just as important as the soda ash.

On page 925, the effect of viscosity with the varying FeO and Fe_2O_3 in the slag. Our experience has been the opposite of Mr. Lowry's conclusions. He says when the total iron oxides are low the slag seems to be thin and active. We have found when the slags are high in iron that they are thin and fluid and when they are low in iron they are liable to be viscous, but you have got to take into account the total manganese in the slag, which has a bigger effect than the iron oxide in thinning slag.

At the bottom of page 925 there is a discussion as to why the soda ash acts to thin and thicken slag. I think that is primarily due to the fact that you get a thin slag which dissolves your lumpy lime. As the lime dissolves you come into a more viscous mixture. Finally you come to a place where the soda ash has done all the work it can, and you have dissolved enough to thicken the slag and there is no more ash or fluorspar left to work on.

W. E. Buck: I would like to ask Mr. Lowry if he has any data on plant work, and if the proportion of heats in which he had to use fluorspar or calcium fluoride to loosen up, or open up, the slag was not just as great with the soda ash as in the average practice of the plant. In checking over I find that he had to use fluorspar in 34 of the 47 heats that he has listed. I know of a number of plants where that would be an excessive use of fluorspar. The heats would shape up without the use of fluorspar in their ordinary practice in a much greater proportion, and I would like to ask what the combination is. He has used in a number of places a combination without, so far as I can see, giving any reference to what the combination is. Perhaps that is because I have not studied the paper thoroughly.

Another point is the cost of the sodium fluoride. What would be the cost of that compared to calcium fluoride? It seems to me that is out of the question, knowing as little as I do about that chemical as a flux for open-hearth use.

C. L. Roth: Might I make just a suggestion based on some experiments in using manganese ore not only as a means of getting rid of sulphur, but otherwise improving basic heats, that it is very important to keep the silica contents of the slag as low as possible. That might seem difficult to a man who is dealing with ordinary materials, but there seems to be a way out of that where it is possible to use a magnetite ore instead of a hematite ore in an open-hearth process. Most of the magnetite ore carries considerable titanium. The titanic oxide will take the place of silica in the formation of a slag and titanium seems to have the property of not combining directly with manganese. In nature it has been found from study of ores that titanium and manganese combine only to a very limited extent. So that if you get titania

into your slag instead of silica the titanium will not combine with the manganese and the manganese will be more effective in removing the sulphur. That is a suggestion that can be worked out by men who have an opportunity to use a titaniferous ore.

I believe that the solution of improving the soundness of steel lies in the direction of converting your CO gas that remains in the mixture into CO_2 in the mixture. In other words, burning it out. It is rather an involved theory, but I think that is the method of approach, and the one thing that seems to be able to help to do that is the presence of manganese oxides in the mixture. The use of some manganese ore in conjunction with titaniferous ore will improve the equality of the steel by burning out the CO gas in the mixture. The CO gas does not seem under all circumstances to have the power of working its way out as a bubble, as a gas, as you know from your results, but you can burn it up right in the mixture, and you can burn it up if you have manganese dioxide there. Now, ordinarily, if you put manganese in a melt you expect the manganese to burn out or to be removed. If you have enough titanium oxide present to combine with the silica it protects the manganese oxide up to the final stages of the process, and then you get to a point where your temperatures play an important part; by having a higher heat (say at least 3200 degrees Fahr.), at certain stages the CO gas will decompose the excess titanium oxide and leave you the metallic titanium in the bath. As your temperature is lowered, while you are waiting for the pouring, that metallic titanium will in turn take any oxygen there is still present in conjunction with any other element in the bath and re-form a titanate which has a tendency to go on the outside of the ingot, contrary to the method of concentration of other impurities, which either gather in the center, bottom or top. Titanium oxide always tends to go to the outside on account of its great affinity for oxygen and oxides, so you get your impurities on the outside of the ingot instead of the interior. All of which suggests a method for improving the soundness of steel by removing the gas, which usually consists of CO gas, without having segregated solid inclusions.

A. L. Feild: I had intended to have a few words to say about Mr. Lowry's paper, but I shall take a few minutes instead to remark upon Mr. Roth's discussion. Mr. Roth brings up the very interesting question of the effect of titania (TiO_2) in open-hearth slag and proposes it as an agent for burning out CO in the steel. It would be very much easier to burn out CO in steel in the open-hearth by means of iron oxide, since it is a much more powerful oxidizing agent than titania and is commonly recognized as such. Unfortunately for Mr. Roth's proposal, however, molten steel invariably contains carbon and when iron oxide or other oxidizing agent acts upon the steel, this carbon is oxidized with CO as one of the reaction products. As long as a metal bath with a carbon content is subjected to refining reactions of oxidation, the formation of CO predominates over the oxidation of CO to CO_2. It is well-known, of course, that the oxidizing action of TiO_2 is, in the circumstances, negligible as compared with that of iron oxide. It is not conceivable, in fact, that TiO_2 can be reduced at all in the basic open-hearth, either by carbon or by CO. The customary procedure in removing dissolved CO from steel is by

the addition of a deoxidizing or reducing agent rather than an oxidizing agent, and is referred to as "killing" the steel. When ferrosilicon is used for this purpose the reaction in question is $2CO+Si=SiO_2+2C$. Granted that TiO_2 could be first reduced into the metal from the slag, the analogous reaction $2CO+Ti=TiO_2+2C$ would undoubtedly proceed. It is barely possible that reduction of TiO_2 might occur in the acid open-hearth in accordance with the reaction $TiO_2+2Fe=Ti+2FeO$.

E. J. LOWRY: (Closure.) The first thing I want to correct is recommending the use of sodium fluoride. I am not recommending the use of sodium fluoride. The object of this paper was to develop a flux which could be used as a substitute for fluorspar. However, the market price of sodium fluoride is 9 cents a pound, which would throw it way out of reach for the steel industry. There has been a process developed which would bring it down to 6 cents a pound, where a volume would be used, and with the lesser amount of sodium fluoride in comparison to the fluorspar used, it might be a possible agent to be used as a fluxing compound.

The first gentleman brought up the question on page 925 that "the viscosity of these slags seems to be controlled somewhat by total percentage of FeO plus Fe_2O_3 present and by relation of Fe Oto Fe_2O_3." That should have been qualified by the statement that the conclusions reached only appertain to the use of soda ash. It seems that when the slag is highly oxidized you do not get the breaking up of sodium bicarbonate into sodium oxide and carbon dioxide. There seems to be a restriction there. I do not know what it is, but the minute your oxide is low you get the sodium oxide, which forms a sodium silicate and thereby reduces the melting point of the slag.

I believe he also brought up the question on page 919 of manganese. It was solely because of the manganese entering in that we took two ladles from the same tap and treated one and did not treat the other. The first test which we ran, we took one ladle and put the soda ash on it and got a marked reduction, and that rather fooled us. To check the result we took one untreated and one treated ladle and the effect of manganese on the reduction of sulphur is shown by the untreated ladle.

The other question was on page 911, the relation of acids to bases. This experiment was performed out of my province altogether. It was performed by one of the large steel companies and given to me just as a matter of record. Whether it has a true bearing on the relation of acids to bases of irons I do not know, but at least in the experiments we ran it does bear importantly on the conclusions that we have. Some one else may have run experiments and they may be totally different in the results.

The other one was that there were combinations—those combinations, although not mentioned in the oral talk, are all listed, and the combinations are soda ash and spar, soda ash and sodium chloride, soda ash and mill scale. Then ordinary glass was used in one instance. I believe we used nine or ten different types of fluxes and combinations, but they are all listed in the paper.

AN EFFICIENT CARBURIZING FURNACE OF THE SURFACE COMBUSTION TYPE

By Dr. A. E. White and E. R. McPherson

Abstract

This article describes a new furnace installation in the Packard Motor Company. The results of tests run on these furnaces for the purpose of determining the temperature—distribution and regulation; production capacity; fuel oil consumption; quality of carburizing and savings over all equipment are set forth. The authors are of the opinion that the ideal type of carburizing furnace is one of the compensating type. Photographs of the furnaces and comparative data of tests run for the new installation as compared with the former box-type furnaces are incorporated.

AN interesting carburizing furnace installation was recently completed at the plant of the Packard Motor Car Company. It consisted of two oil-fired surface combustion furnaces, each one designed to handle 80 boxes of a gross weight of 250 pounds per box.

The furnaces, which are used to carburize transmission gears, pinions, pinion shafts, etc., are 25 feet long, 4 feet wide and 22 inches high to the spring line of the arch—inside dimensions. They are divided into a heating chamber where the work is maintained at the desired temperature for the time necessary to produce the required depth of case. The walls are of refractory brick, backed up with insulating material designed to procure the maximum amount of heat retention with the minimum amount of heat conduction, or loss. The furnaces are enclosed in a heavy steel casing held together with steel buck-stays. The steel parts to be treated are packed in a carburizing material in metal boxes, which are placed on tracks, in an inverted position, and pushed through the furnace by means of hydraulic jacks, as shown in Fig. 1.

Each furnace is equipped with four oil burners, although gas could have been used equally as well, two to each chamber, firing longitudinally into the combustion chamber or duct. The walls and roof of these ducts are composed of a highly conductive ma-

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. Of the authors, Dr. A. E. White, is director of engineering research, University of Michigan, Ann Arbor, Michigan, and E. R. McPherson is associated with the Packard Motor Car Company, Detroit.

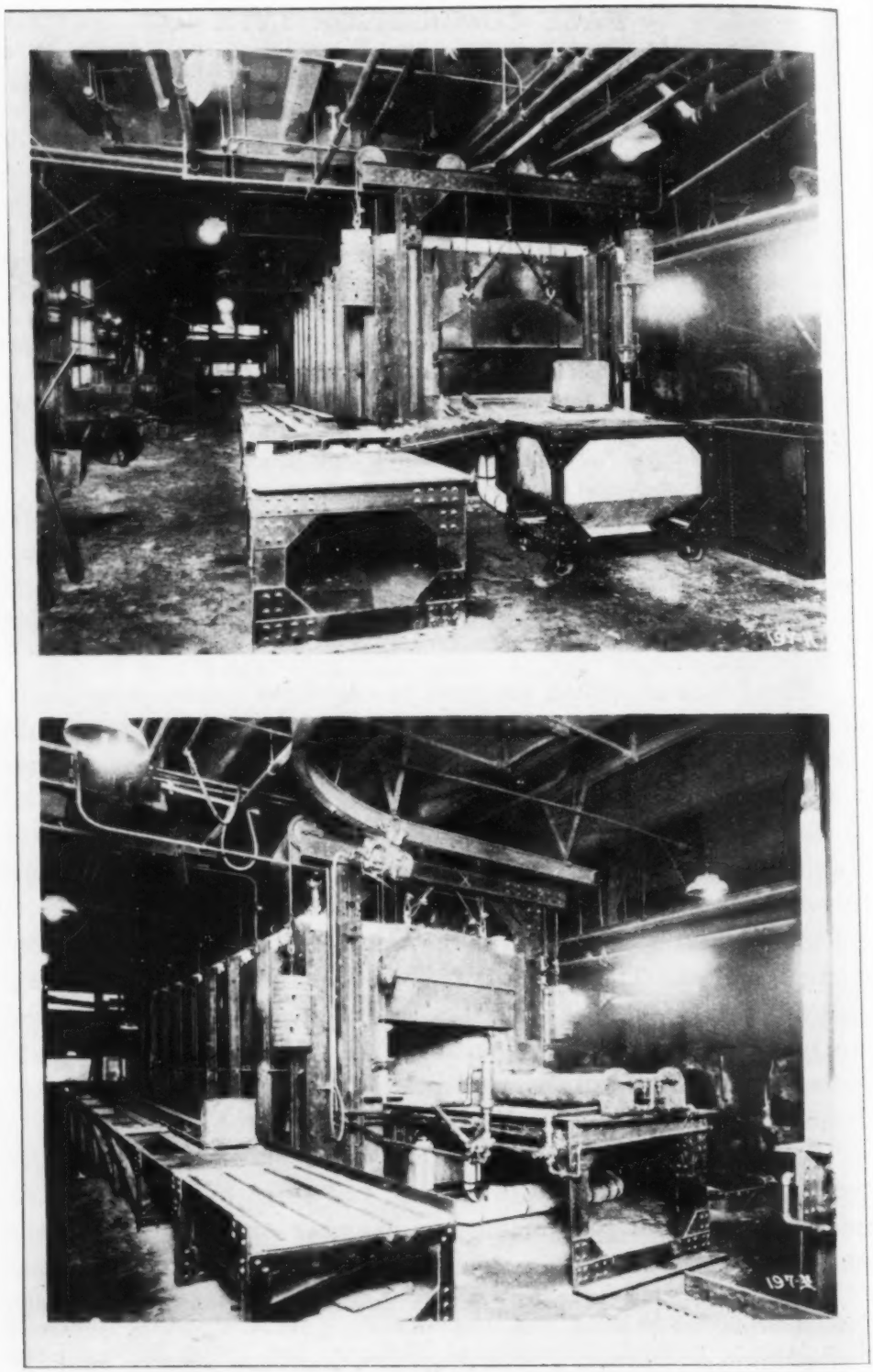


Fig. 1—Photographs Showing the Installation of Surface Combustion Carburizing Furnaces Described in this Paper.

Carburizing

terial having a heat transfer rate approximately nine times that of brick. The products of combustion, after entering the heating chamber, are recirculated by means of a patented construction, thereby increasing the content of the noninflammable products in the combustion mixture. This has the effect of lowering the combustion temperature and smoothing out localized high temperature zones. Recuperation is another feature of these furnaces, and all waste gases must leave the furnace through the recuperator chamber, where the air going to the oil burner is preheated.

Some months ago a number of tests were run on these furnaces for the purpose of determining the following qualities.

A—Temperature—distribution and regulation
B—Production capacity
C—Fuel oil consumption
D—Quality of carburizing
E—Savings over all equipment

The results of these tests are recorded and discussed in this paper.

A. Temperature—Distribution and Regulation

Five thermocouples were located in one of the furnaces as shown in Fig. 2. These were inserted through the roof of the furnace between the two rows of boxes; the couple ends extending from four to six inches below the top of the boxes. They were kept in their respective positions during the day of the test.

The readings from thermocouple No. 1 are given in Fig. 3. This thermocouple was located six and one half feet from the inside of the charging doors or at the fifth pair of boxes from the charging door. The thermocouple was attached to a recorder. The automatic burner control for the heating zone was set at 1550 degrees Fahr.

The temperature readings taken from the chart show a periodic variation of from 15 to 20 degrees Fahr. due to the insertion of cool carburizing boxes. This periodic variation of temperature at the charging end cannot be materially decreased, due to the specific heat of the cool charge and the heat losses due to the opening of the door.

The condition in the soaking zone—the zone of the furnace in which close control is most desired—is given in Fig. 4. The furnace was purchased with a guarantee of 10 degrees Fahr., con-

trol and these chart readings indicate this control was to all intents and purposes, reached.

A short time test for the vertical temperature distribution was made. This was done by inserting a triple pointed thermocouple between the box rams at the beginning of the soaking zone.

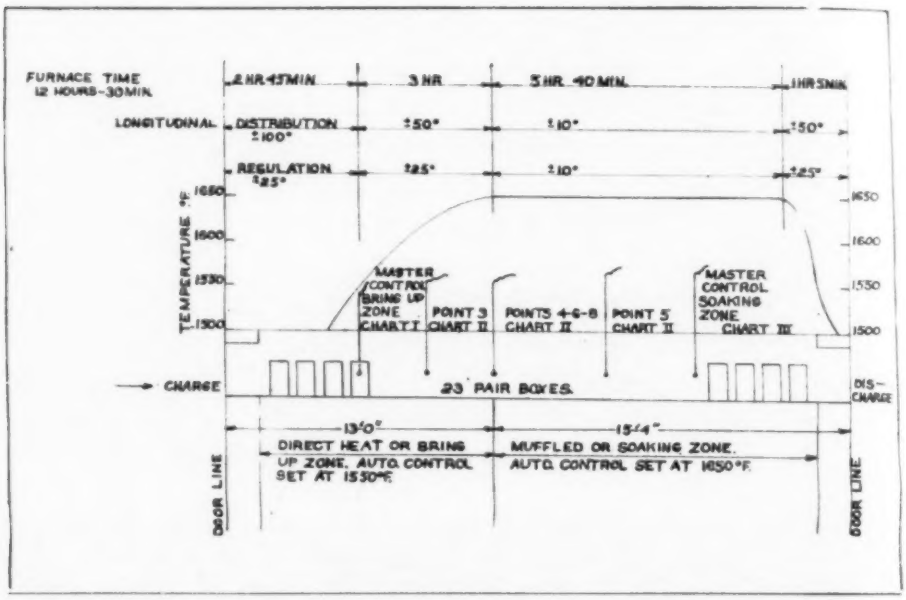


Fig. 2—Summary Chart of Temperature Distributor and Regulator for Continuous Carburizing Furnace.

Each of the three points was two inches above the bottom, middle and top of the box level, respectively. The test showed no discernible temperature difference at the three elevations.

In addition, the temperature inside four successive boxes was measured by inserting a preheated thermocouple inside partially opened boxes and noting the maximum temperature reached. In each case this was 1610 degrees Fahr. The actual temperature, however, was believed to be 15 to 20 degrees Fahr. higher as it was difficult to insert the tip of a thermocouple into a partially opened box more than a few inches. Without any question, however, the temperature of the stock is above the minimum quenching temperature specified—namely 1550 degrees Fahr.

B. Production Capacity

The furnaces were guaranteed for a production of 80 boxes

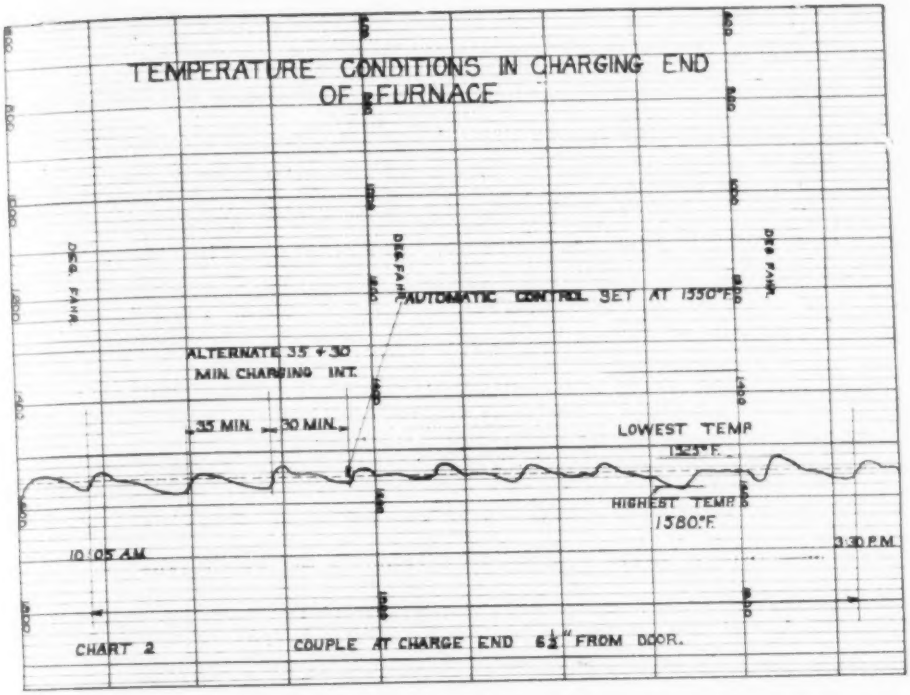


Fig. 3—Curve Showing Temperature Condition in the Charging End of the Furnace.

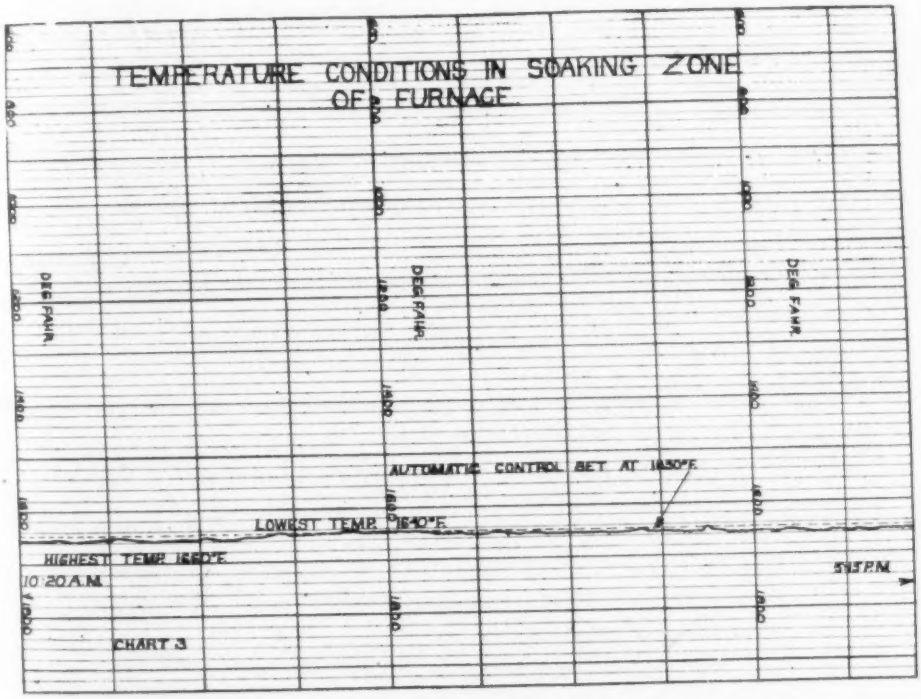


Fig. 4—Curve Showing Temperature Condition in the Soaking Zone of the Furnace.

of a gross weight of 250 pounds per box per day. This would give each furnace a gross output of 833.3 pounds per hour.

The actual production at the time of the test was 1115 pounds of gross weight per hour. In other words the furnace exceeded its guaranteed production capacity by 33 per cent.

The distribution of the weight in each box follows:

Box	147 pounds
Lid	65 pounds
Carburizing Compound	20 pounds
Gear Charge	64 pounds
Total	296 pounds

C. Fuel Oil Consumption

The fuel oil consumption was measured by using alternately two, four-gallon graduated tanks which were connected into the main furnace feed line leading to all of the four furnaces.

Time of test	9:35 A. M. to 5:10 P. M.—7 hr. 35 min.
Oil consumed at 97 degree Fahr.	48 gallons
Gross weight discharged during test	8228 pounds
Net weight discharged during test	1726 pounds
Number of boxes charged	28
Average gross weight of boxes	64 pounds
Specific heat of charge	0.165 (estimated)
Heating value of oil	18600 B. T. U's per pound
Pounds of oil per gallon	7.2 pounds
Furnace temperature	1650 degrees Fahr.
Room temperature	80 degrees Fahr.

Oil Consumption

$$\frac{48 \text{ gal.}}{7.584 \text{ hours}} = 6.32 \text{ gallons per hour.}$$

$$\frac{8228 \text{ lbs.}}{48 \text{ gal.}} = 171 \text{ pounds—gross weight discharged per gallon during test.}$$

$$\frac{1726 \text{ lbs.}}{48 \text{ gal.}} = 36 \text{ pounds—net weight discharged per gallon during test.}$$

$$\frac{28 \text{ hours} \times 296 \text{ lbs.}}{48 \text{ gal.}} = 173 \text{ pounds—gross weight (average in furnace) per gallon.}$$

$$\frac{28 \text{ boxes} \times 64 \text{ lbs.}}{48 \text{ gal.}} = 37.4 \text{ pounds—net weight (average in furnace) per gallon.}$$

Furnace Efficiency

$$\frac{\text{Pounds production per gallon} \times \text{specific heat} \times \text{temperature Difference}}{\text{Heat supplied}} =$$

$$\frac{172 \text{ lbs.} \times .165 \times (1650 - 80°\text{F})}{7.2 \text{ lbs.} \times 18600 \text{ B.T.U's}} = 33.3 \text{ per cent gross efficiency} =$$

$$\frac{36.7 \text{ lbs.} \times .165 \times (1650 - 80°\text{F.})}{7.2 \text{ lbs.} \times 18600 \text{ B.T.U's}} = 7.1 \text{ per cent net efficiency.}$$

The furnaces were guaranteed to treat 80 pounds of gross weight per gallon of oil. As a matter of fact, they practically doubled their guarantee by treating 172 pounds of gross weight per gallon in place of the 89 pounds specified.

They showed 33.3 and 7.1 per cent gross and net efficiency respectively. This is unusually high for oil-fired furnaces. Most oil-fired furnaces do not show a gross efficiency beyond 5 to 10 per cent or a net efficiency beyond 2 to 2.5 per cent.

D. Quality of Carburizing

Test pieces taken at different positions from successive boxes during a regular production run showed regularity in case depth as recorded below.

	Steel	Case Depth in Inches
1	5% Nickel Steel	0.039
2	5% Nickel Steel	0.038
3	5% Nickel Steel	0.035
4	5% Nickel Steel	0.035
5	5% Nickel Steel	0.035
6	5% Nickel Steel	0.037
7	Plain Carbon	0.042*
8	Plain Carbon	0.040*
9	Plain Carbon	0.042*

*Repeated tests of stock showed variation 0.0165 to 0.0425 inches.

E. Savings of Continuous Carburizing Furnaces

These two carburizing furnaces replace 31 stationary oil-fired hearth-type furnaces.

A comparison of the operating costs of the two installations shows a marked saving to the credit of the new furnaces. This saving on a very conservative basis, amounts to $45,520.00 per year, which is 82.8 per cent of the cost of the new installation. The saving is due to a reduction in the number of men required, a material saving in the carburizing compound and a material reduction in the fuel cost, as these new furnaces consume only slightly more than 1/7 of the oil required for the older installation.

No mention is made of the saving due to the increased life of the carburizing boxes. This is a very material factor, though it is one on which there is apparently little information in any of the heat treatment plants in the country.

For furnaces of the capacity discussed in this article, a life

of 5000 hours for carburizing boxes is considered fair. A furnace operation per year of 6000 hours would require an annual expenditure per furnace for boxes and covers, of $51,750.00. This figure is based on the assumption that the carburizing boxes sell for 95 cents per pound, with a 20 cent rebate per pound upon the return of the old box stock. If box life were 7000 hours, the cost would be $36,964.00 and if the life were 14,000 hours the annual box cost would be $18,483.00. It is appreciated that these figures are somewhat high, because of the fact that it is possible to procure carburizing boxes in quantities at lower prices than those just mentioned.

Likewise, it should be pointed out that the deterioration of carburizing boxes is probably due more to rapid heating and cooling than it is to the influence of the conditions within the furnace. Unless a direct flame heats the box it should not undergo rapid deterioration unless it is abused by rapid heating and cooling. So far as the installation at the Packard Motor Car Company is concerned, the furnace conditions are such that they would get the same box life as electrically heated furnaces.

The ideal type of carburizing furnace is one of the compensating type. In such a furnace the boxes are slowly brought up to heat and are slowly cooled. This results in making it possible to efficiently utilize the heat in the box as the box cools from the carburizing temperature and likewise such a condition tends to prevent to the maximum warpage of the box. Therefore, it is safe to predict that the life of carburizing boxes in compensating furnaces, would be double if not triple that in the ordinary type of carburizing furnace. It is appreciated that compensating furnaces cannot be used for all carburizing operations, as in many operations it is desired to quench the stock from the carburizing temperature. Yet, where it is possible to use compensating furnaces, box life saving amounting in most installations to thousands of dollars per year would be effected.

The comparative data for the new installation as compared with the former box-type furnaces, follows:

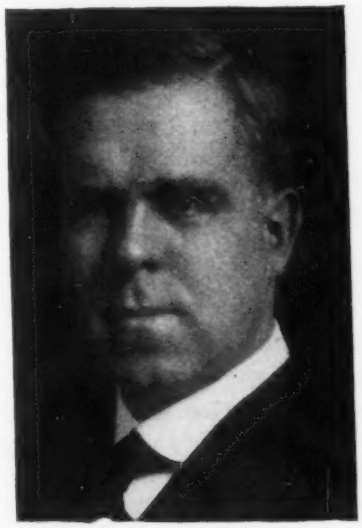
	New Installation	Replaced Furnaces
Net output gear stock per hour	482 lbs.	482 lbs.
Compound used per year.....	226 tons	452 tons
Labor cost per year	$12,500.00	$31,200.00
Oil cost per year	$ 4,750.00	$29,000.00

Compound cost per year	$13,550.00		$27,120.00
Total yearly operating cost not including maintenance ...	$30,800.00		$87,320.00
Actual cost of two furnaces complete		$55,000.00	
Interest, depreciation, insurance taxes—20% of $55,000.00		$11,000.00	
Total yearly charge		$41,800.00	
Total yearly saving $87,320.00 — $41,800.00 =		$45,520.00	
Return on investment per year $\frac{\$45,520}{\$55,000}$ =		82.8%	

The Authors

A. E. White, Director, Department of Engineering Research, University of Michigan, Ann Arbor, Michigan, was born in Plainville, Mass., in 1884.

Prof. White graduated from Brown University in 1907 and received his Master's Degree from Harvard



A. E. WHITE

E. R. McPHERSON

University in 1908. He was awarded a doctor's degree from Brown University in 1925 in recognition of the splendid work he has done along metallurgical lines. He has contributed much to the literature in the iron and steel field and many of his papers, especially those along the lines of heat treatment, have been published in Transactions.

He has been actively associated and connected with the work of the American Society for Steel Treating,

having been chairman of the committee of amalgamation of the Steel Treating Research Society of Detroit and the American Steel Treaters' Society of Chicago. Following the adoption of the committee's recommendation in Philadelphia in 1920 Prof. White was elected the first president of the American Society for Steel Treating.

E. R. McPHERSON has since 1923 been a member of the construction and maintenance division of Packard Motor Car Company in the capacity of general plant engineering design work, of which he is now in charge. He obtained his early education in Yuma, Arizona.

In 1918 he was appointed to the United States Naval Academy, Annapolis, Md. He graduated in 1922 and held commission in the United States Naval Reserve Corps in lieu of active service.

His native home is Pittsburgh.

DISCUSSION

E. C. OSTERMAN: I did not receive an advance copy of Dr. White's paper, as otherwise I would liked to have prepared a more thorough discussion of the same.

I question Dr. White's statement that the compensating type of carburizing furnace is the ideal one, especially since this type of furnace retains the many unsatisfactory features of the old and more or less antiquated batch type furnace, including such items as the initial cost of boxes, the high labor cost in packing and handling them, and the low overall efficiency of such a furnace. From Dr. White's itemized statement of the weight of each box, and of the compound and gear charge in it, you will note that the total weight is 296 pounds. If the compensating furnace were perfect and if 100 per cent of the heat generated was delivered to the furnace the operation would only be about 21 per cent efficient, because of the total weight of each unit of charge of, 296 pounds, only 64 pounds is gear charge.

Considering the great initial cost of the installation, of the boxes which must be handled, and the labor cost in packing such boxes, the hourly output of the equipment at 482 pounds is not exceptional. Furthermore, there is no reason why a furnace of the compensating type would give a more uniform depth of case hardening than any batch type furnace, and whatever objectionable features there may be in the batch type furnace, that is the furnace in which you load a box or two, are retained in the compensating furnace. The feature of pushing boxes through the furnace mechanically only has been added to the old type of carburizing furnace.

It would appear that the uniformity of case would favor the ordinary batch type furnace because of the fact that in the compensating furnace with cold boxes being heated on one side only neither the box nor its contents attain the carburizing temperature uniformly.

In a previous paper some question as to the controversy between oil,

gas and electricity was raised. I do not think that is quite apropos because the gain made in that instance by the electric furnace was due to the type of installation and not to the type of fuel. Such a furnace might have been designed to use any other fuel, and equal or perhaps greater savings would have been shown due to similarly elaborate recuperative features incorporated in its design.

F. A. HALL: I would just like to say a word in regard to Mr. Osterman's remarks. He said that in the box type of furnace or in a continuous type of furnace, such as Dr. White described, the fuel was not important. I agree with him. Dr. White made a remark that we should not compare all of the present furnaces in operation with the more modern type of furnace. I contend that today we can design and build furnaces for any fuel, gas, oil or electricity which will give the same uniformity of heat distribution and the same accuracy and sensitivity of control, so the type of fuel to be used in any furnace, box or continuous, depends upon local conditions and economy.

Mr. Osterman did not bring out what he really had in mind. We all know the type of equipment he is interested in and it is a very good type. But there will still continue to be many applications where the loading of material into pots will be the desirable way to handle it for carburizing conditions, and in that case we will have to contend with our lower efficiencies, due to the weight of pots and packing material.

E. C. OSTERMAN: The ratio of carburizing compound to gear charge, according to Dr. White's paper, was roughly one to three. In the rotary retort carburizing machines using compound, the ratio of work to compound is usually 20 to 30 pounds of work to one pound of compound. In some cases the ratio of work charged to compound used is as great as 40 to 1; that is, 800 pounds of work have been carburized using only 20 pounds of compound.

F. A. HALL: I just want to add another word that has occurred to me from the standpoint of a furnace designer. I do not know how many of you fellows analyzed the results given in this paper, but you are approaching very near the maximum efficiency possible with that type of equipment. In other words, your flue losses represent practically all the loss; your radiation loss is very low and you are reaching almost the maximum possible efficiency that could be obtained.

DR. A. E. WHITE: I am very glad, indeed, to be corrected in regard to anything that I may have left with you with regard to the fact that I consider these furnaces the ideal type of carburizing furnaces. I do not consider any furnace an ideal type of carburizing furnace until we can get away entirely from the carburizing box, because if you will analyze the weights here, you will find that we are actually heating per box something over 200 pounds of dead box material for the purpose of doing something on 64 pounds of material. Yet I do not quite at this moment know how we are going to reach this ideal condition in all cases. I appreciate that carburizing is done in cases in which no carburizing boxes are used. Yet you also appreciate that those furnaces are not applicable, so far as I know, to all types of material which it is desired to carburize. And, therefore, I do not quite see where our Elysian day has arrived. And yet I think we all agree that we

are hopeful sometime or other to be able to cut down materially the weight of dead, useless material which we are daily putting through our furnaces in the carburizing operation. Nor did I wish to convey the impression that there is no field for a batch type furnace. I realize that there are many concerns that are engaged in small carburizing operations that will have to use a furnace for the batch type. As a matter of fact, this record given here could have been an efficiency record of a batch type furnace just as much as it could have been an efficiency record of a continuous furnace in all respects, possibly with the exception of the labor, that is, the efficiency of the furnace might have been nearly the same.

I think, too, that another thought has been opened up, namely a study of the amount of carburizing compound which is necessary for a given operation. And it is possible through a closer analysis of operating costs for plants to use less carburizing compound than some of them are now using. That cut down in cost must be done with discretion, because one must not cut the carburizing compound down to a point such that they will not get a sufficient depth of carburizing nor a uniform quality of carburizing.

E. C. OSTERMAN: By way of emphasis may I again call attention to the ratio of compound to work as given in Dr. White's paper. It is slightly less than one pound of compound to three pounds of work. Using rotary retort carburizing machine it is possible to carburize using one pound of compound to 20 to 30 pounds of work and in some cases this ratio has been reduced to one pound of compound to 40 pounds of work.

Dr. White agrees that it would be a mighty fine thing if the carburizing box and lid could be dispensed with. A way to do this has not been found but the rotary carburizing machine more nearly approaches this ideal than anything which has been developed up to this time. The ratio of work to retort is 1 to 1 and in many cases much less, perhaps ¾ of a pound of container to 1 pound of work, whereas with the equipment under discussion the ratio is 212 pounds of box to 64 pounds of work, or more than three to one.

Furthermore the box must be heated each time that a charge is placed in the furnace; but after the first charge, work goes into the red hot retort of the rotary carburizer and not into a cool box which must be heated.

Dr. White brought to our attention the fact that for many kinds of work boxes must be used. This may be so but rotary carburizers should certainly be used for the work for which they have proven themselves well adapted. And when it is considered that work ranging from parts weighing only 1/6000 of a pound up to pieces weighing 500 pounds each are being treated in the same machine we will have to agree that it is rather a versatile machine at that. For other classes of work such as rods, cam shafts, crank shafts and large gears which cannot be conveniently treated in the rotary machines a vertical retort carburizing furnace has been developed which operates on much the same principal as the rotary carburizing machine. In it gears up to 28 inches in diameter are being successfully treated.

H. B. KNOWLTON: I would like to ask Dr. White a question which is purely for information. What is the effect of passing into the cooling zone

of the recuperative furnace upon the carburizing conditions in the pot? Will there be any decarburizing action while the pot temperature is dropping from the maximum carburizing temperature to the lowest temperature at which carburizing or decarburizing may take place? It has been reported that when the pot temperature drops slightly there is a tendency for air to be sucked in under the lid, probably producing an atmosphere rich in carbon-dioxide at the top of the pot. It is claimed that such conditions will cause decarburization. Do you find this to be the case?

DR. A. E. WHITE: I do not know as I can answer that exactly. I do not think we have enough information and data on the subject to answer it exactly. Of course, we were speaking of the value of the compensating type of furnace in carburizing only for that type of material which is to be slowly cooled and also I would assume that any designing engineer designing a compensating type of furnace would see to it that the soaking zone is of sufficient capacity so that the metal can be held at heat for the required length of time. In the cooling zone the action you would get in the atmosphere would be duplicated, excepting that the heat in the boxes undergoing cooling would be absorbed by the boxes that were about to undergo heating. If there was any sucking of air into the boxes I would assume that the air would be sucked into the boxes that were in the atmosphere even more quickly than they would be in the furnaces.

Likewise, in some of these compensating types of furnaces the lids are on the bottom and therefore the air would, the heavier monoxide air has a better opportunity, I would say, to be entrapped and held in than it would be with the lids on top.

W. B. CROWE: In my opinion, I do not consider that the box itself, from the standpoint of dead-weight, causes as much time and heat loss as the insulating property of the carburizing material.

In the study of the application of gas carburizing, it appears that a pronounced reduction of these heat and time losses through lag, would be an important consideration.

W. A. TIMM: Mr. Chairman, inasmuch as there has been considerable discussion this morning regarding the use and life of carburizing boxes, I wish to point out that the electric recuperative furnace described in my paper was used exclusively for annealing.

At the present time, all parts are annealed in heat resisting alloy boxes which weigh practically as much as the parts put in them.

The Western Electric Company, Incorporated, has perfected a method of annealing, in which the parts are piled either directly upon the top of the furnace car or are put in perforated metal baskets which are placed on the car top. A single heat resisting alloy hood is then lowered over this load and is sealed to the car top with foundry loam. This method materially reduces the amount of tare metal to be heated.

Small iron castings such as covers for repeating and retardation coils are simply piled upon the car top and are annealed without any protection whatever.

CYANIDE BRITTLENESS

By V. E. Hillman and E. D. Clark

Abstract

This paper deals with a discussion of cyanide brittleness and points out that the popular misconception in reference to the brittleness of the core has been dispelled. The authors discuss the mechanism of rupture with the case intact and the case removed and substantiate the results of their investigation by curves and photographic evidence.

LOW carbon steel held at 1500 degrees Fahr. for 30 minutes and quenched in the usual manner in water will not respond to heat treatment to any marked degree. The metal remains tough and ductile, and the tensile strength and elastic limit are only slightly affected. On the other hand, low carbon steel immersed in a molten bath of sodium cyanide, salt and soda ash for 30 minutes at a temperature of 1500 degrees Fahr. and subsequently quenched in water, possesses a martensitic case of 0.005 to 0.006 inch in depth and a core which invariably appears to be extremely brittle. Such fragility is contrary to well known metallurgical experience. The lack of toughness in the core is attributed by some writers to the absorption of nitrogen. It is said that cyanide embrittles the steel, due to the presence of nitride patches and needles. This may be true insofar as the case is concerned, but the core is not similarly affected. Admittedly Fe_2N or Fe_3N_2 contributes to the mineral hardness of the superficial nitrogenous case, but the afore-mentioned compounds have little or no effect upon the core. It is not the intention of the authors to challenge the data which has been recorded by other investigators, but the aim and purpose of this paper is to set forth the results obtained in this laboratory.

Six standard tensile test specimens were immersed in a commercial cyanide bath at 1500 degrees Fahr. for 15 minutes and then quenched in water. The afore-mentioned procedure was repeated at 30, 45, and 60-minute intervals. A total of 24 specimens were quenched. The percentage reduction of area and tensile strength in pounds per square inch were noted. The reduc-

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. Of the authors, V. E. Hillman is director of chemical and metallurgical research, and E. D. Clark is metallurgist, of the Crompton and Knowles Loom Works, Worcester, Mass.

tion of area furnishes a valuable indication of the ductility of the metal under examination. Graphical data is presented in Fig. 1. The percentage reduction of area incident to water quenching varies inversely with the time of immersion. Extreme brittleness is noted at 30, 45, and 60-minute intervals. The cross sectional area of the specimens presented the character of a quickly made fracture with a crystalline appearance. A crystalline fracture usually results from intercrystalline failure. The brittleness of the metal becomes more pronounced as the period of cyaniding increases. The percentage reduction of area decreased from 62 to 0 per cent. A 30-minute cyanide treatment, which conforms to standard shop practice, gave rise to a reduction of area of only 4 per cent. By the same token, the tensile strength of the metal increases as the period of immersion is prolonged. This value is also an index of brittleness. It will be observed that the tensile strength increased from 62,000 to 95,000 pounds per square inch for the water quench. These graphs are introduced to establish the apparent brittleness of the core of casehardened products. Similar results were obtained with oil quenching, although to a lesser degree. The physical properties of the annealed test specimens prior to experimental heat treatment were, tensile strength—

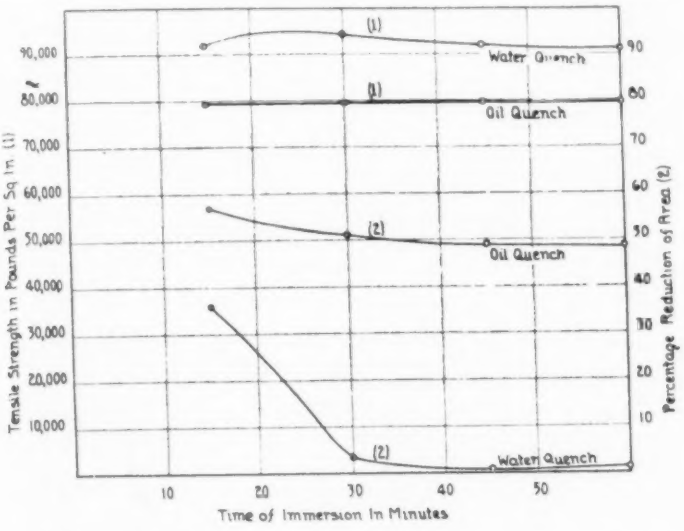


Fig. 1—Curves Showing the Tensile Strength of Standard-Size Test Specimens which were Heated in a Cyanide Bath at 1500 Degrees Fahr. for Various Periods of Time and Quenched in Water. Analysis of Steel Carbon 0.13%, Manganese 0.32%, Phosphorus 0.097%, Sulphur 0.109%. Analysis of Cyanide Bath: Sodium Cyanide 43.5%, Sodium Chloride 44.5%, and Sodium Carbonate 12.0%.

62,500 pounds per square inch; reduction of area—62 per cent.

Forty-two additional standard test bars were cyanided, in groups of six, for varying lengths of time at 15-minute intervals up to 60 minutes and thereafter at ½-hour periods until a total of 2½ hours were consumed. The specimens were taken from the molten bath and cooled in sand, and the superficial case was removed by turning the specimens in a lathe. The resulting diameter between shoulders was 0.4 inch. The test pieces were reheated to a temperature of 1500 degrees Fahr. in an electric furnace, quenched and tested. The cross sectional area of the specimens revealed a fibrous appearance which presented a grayish mass of

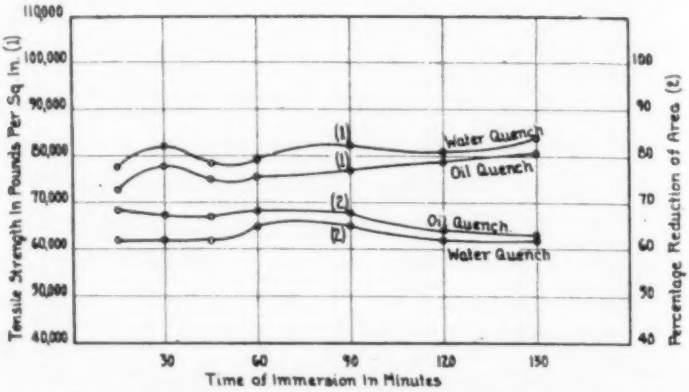


Fig. 2—Curves Showing the Tensile Strength of Standard-Size Test Specimens Heated in a Cyanide Bath at 1500 Degrees Fahr. for Various Intervals of Time as Indicated. Cooled in Sand. The Diameter Between the Shoulders was then Turned Down to 0.400 Inch and the Specimen Reheated to 1500 Degrees Fahr. and Quenched. Analysis of Steel and Bath Given in Fig. 1.

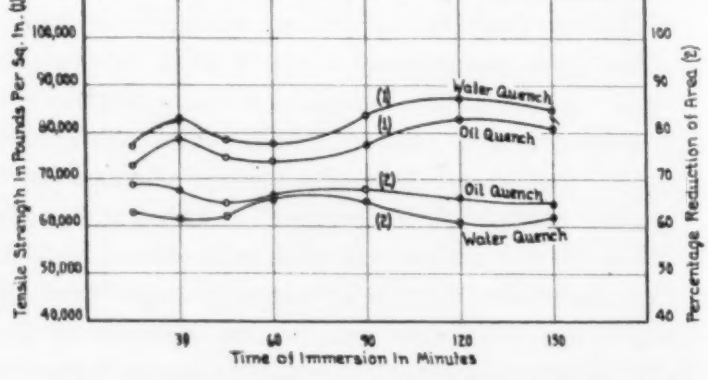


Fig. 3—Curves Showing the Tensile Strength of Standard-Size Test Specimens Heated in a Cyanide Bath at 1500 Degrees Fahr. for Various Periods of Time as Indicated and Cooled in Sand. The Diameter Between the Shoulders was Turned Down to 0.300 Inch and then Reheated to 1500 Degrees Fahr. and Quenched. Analysis of Steel and Bath are Given in the Caption of Fig. 1.

rugged broken ends. Fig. 2 sets forth the results obtained. An examination of the water quenching curve which records the percentage reduction of area indicates that no brittleness is in evidence. The value is nearly constant. That is to say, the percentage reduction of area remains in the vicinity of 62 per cent,

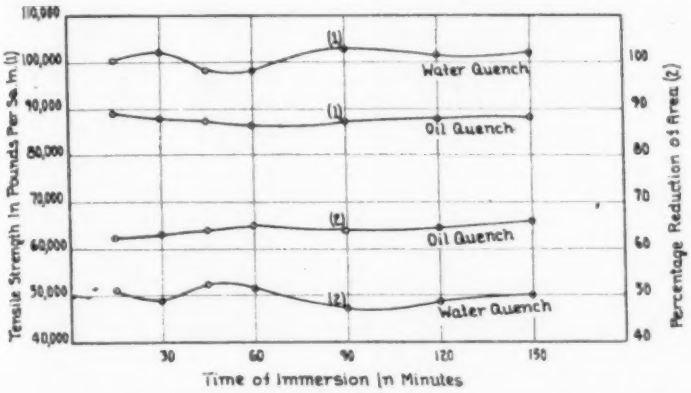


Fig. 4—Curves Showing the Tensile Strength of Standard-Size Test Specimens which were Heated in a Cyanide Bath at 1500 Degrees Fahr. for Various Intervals of Time as Indicated and Quenched. The "Case" was Removed by Grinding. The Diameter Between the Shoulders was Turned Down to 0.400 Inch. Analysis of Steel and Bath are Given in the Caption of Fig. 1.

notwithstanding that the specimens were immersed in the cyanide bath for varying lengths of time. The tensile strength curve shows precisely the same tendency to remain constant. It is to be noted that the curve manifests a tendency to follow the 80,000-pound per square inch abscissa. Oil quenching data is incorporated in Fig. 2 as a matter of reference.

To substantiate the results obtained, a third set of forty-two specimens were machined. A set of six comprised each group. The test bars were cyanided, cooled in sand, turned in a lathe to 0.3 inch in diameter, reheated in an electric furnace and quenched. The instant procedure was precisely the same as that adopted for the construction of Fig. 2, save that the specimens were turned to 0.3 instead of 0.4 inch diameter. (Fig. 3.) Again brittleness is lacking. This statement is borne out by the percentage reduction of area and tensile strength values.

As a final proposition, forty-two specimens were again cyanided for varying lengths of time, and then quenched. The case was removed by grinding with the aid of a copious flow of water. The diameter of the specimen between shoulders was 0.4 inch. Fig. 4 illustrates the results obtained under the afore-mentioned

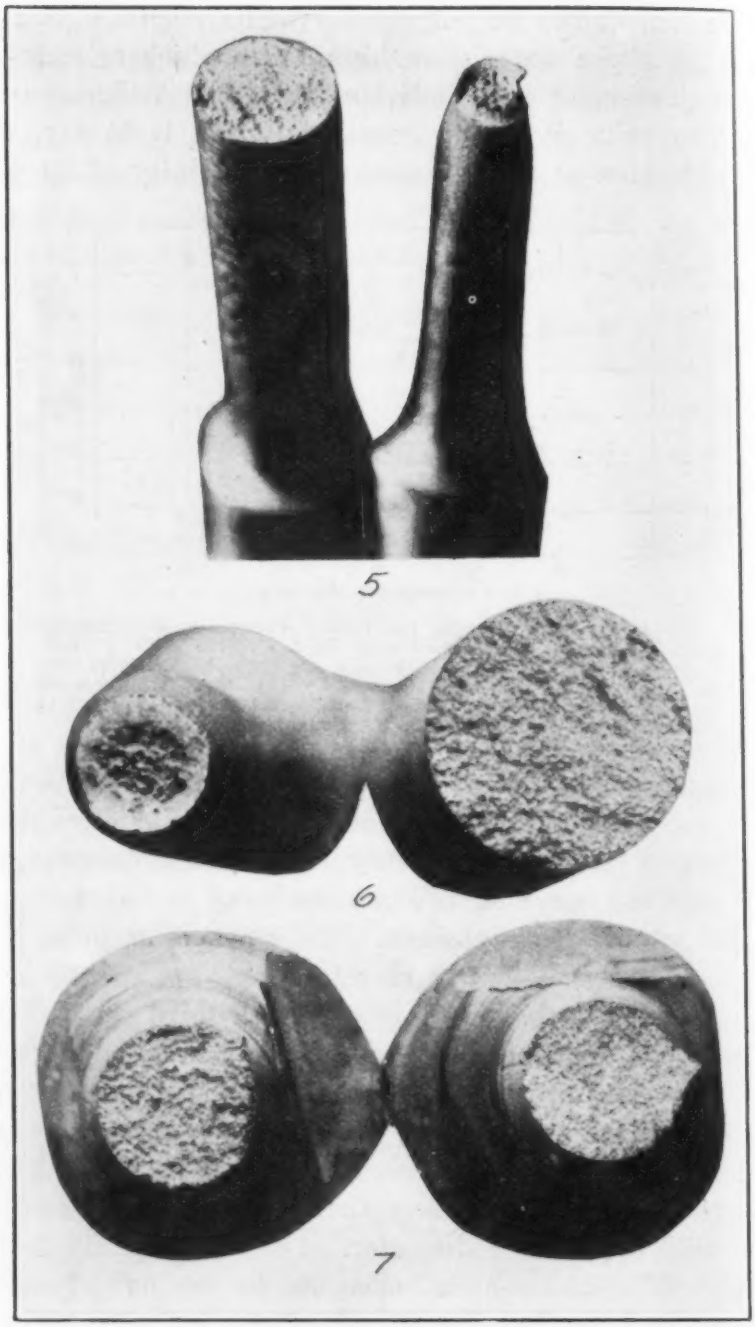


Fig. 5—Photograph Illustrating the Character of the Specimens Referred to in Figs. 1 and 2. The Contrast Between the Brittle and Ductile Fracture is Plainly Discernible. The Two Samples Show a Wide Variance in Physical Properties. Mag. 2x. Fig. 6—Photograph Showing the Fracture (on the Left) Resulting After the "Case" was Removed. The Fracture on the Right is that Resulting by Testing of the "Case" Intact. Mag. 2x. Fig. 7—Photograph Showing Fractures of Cyanided Studs Which Failed in Service. There is Practically no Ductility in These Specimens as Shown by the Fracture.

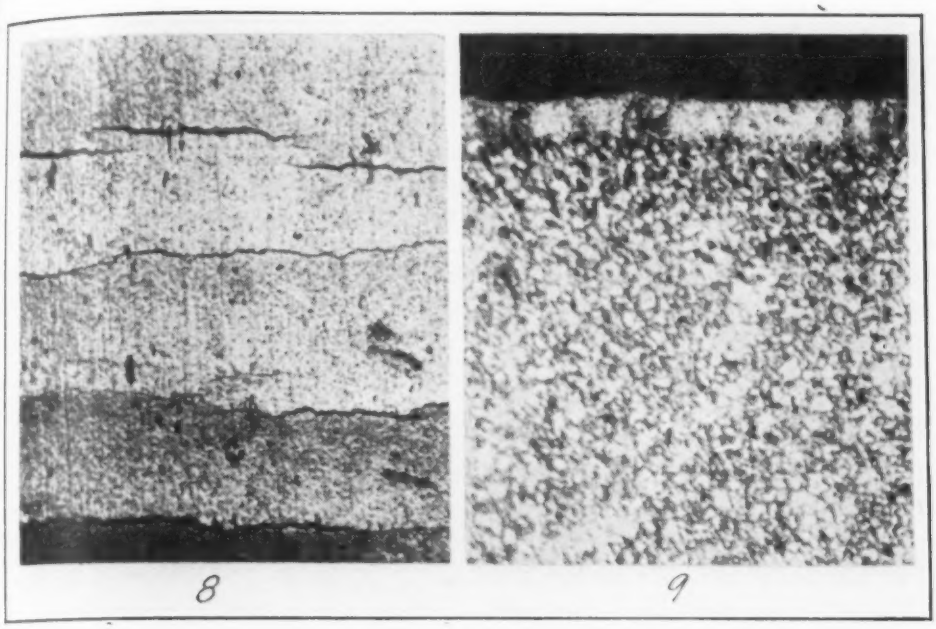


Fig. 8—Photomicrograph Showing the Cracks which Appear on the Surface of a Cyanided Test Specimen when it is Subjected to Stress. These Fissures Act as Seats of Rupture, thereby Causing the Ductile Core to Break "Sharp." Grinding Away the "Case" Removes the Point of Origin or Region of Incipient Breakage. Mag. 52x. Fig. 9—Photomicrograph of a Specimen Cyanided for 45 Minutes at 1500 Degrees Fahr. and Quenched in Water. Depth of Case 0.005 Inch. Mag. 100x.

procedure. Ductility is still in evidence. The percentage reduction of area and tensile strength in pounds per square inch substantiates this viewpoint. The water curves show a slight average increase in tensile strength and a corresponding decrease in the percentage reduction of area, as against similar curves illustrated in Figs. 2 and 3. The extreme brittleness evident in Fig. 1 is still lacking, however.

The idea occurred that the brittleness of the core after the removal of the case might be more pronounced if the specimens were cyanided at lower temperatures. Mention has been made of encountering a critical range wherein the brittleness of the core is more evident. A number of specimens were cyanided for varying lengths of time (15 minutes to 2 hours) at temperatures of 1400, 1425, 1450 and 1475 degrees Fahr. The standard specimens were quenched in water. The diameter between shoulders was ground to 0.4 inch. The results obtained on the tensile machine duplicated the properties plotted in Fig. 4. The reduction of area hovered around 50 per cent. The values obtained indicate that the core is not affected at the afore-mentioned temperatures.

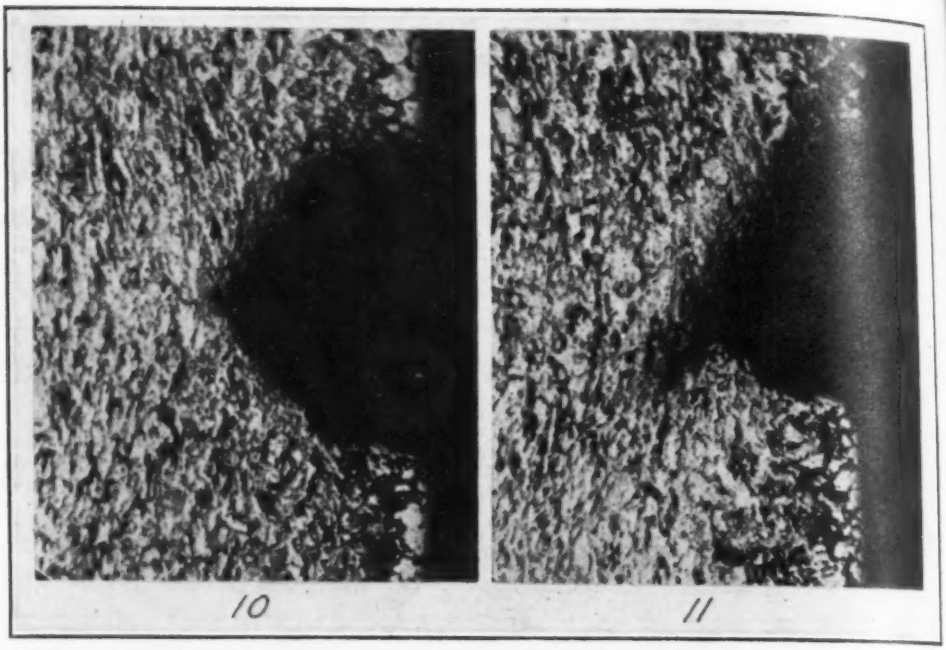


Fig. 10—Photomicrograph of a Specimen Cyanided for 45 Minutes at 1500 Degrees Fahr. and Quenched in Water. The Photomicrograph Illustrates the Manner in which a Cyanide Case Fails when Subjected to Stress. The Brittle Outer Layer "Snaps," Whereupon Rupture is Rapidly Transmitted Through the Ductile Core. The Brittle Case Acts as a Seat of Rupture. The Photomicrograph Illustrates the Appearance of a Longitudinal Section of Metal which as been Stressed with the Case Intact. Mag. 100x. Fig. 11—Photomicrograph of a Specimen Cyanided for 45 Minutes at 1500 Degrees Fahr. and Quenched in Water. A Cyanided Specimen which has been Subjected to Stress. The Path of Rupture Swerved Slightly when it Encountered the Tough Ductile Core. The Load was Released Before Breakage Occurred. If the Metal were Pulled Asunder a Sharp Crystalline Structure with Approximately 3 Per Cent Reduction of Area would have Manifested Itself. Mag. 100x.

The decrease in the percentage reduction of area is occasioned by the slight response of low carbon steel to heat treatment.

The opinion was advanced that the apparent brittleness of the core with the case intact is probably due to the strained condition of the metal incident to quenching. In view of the suggestion, a number of specimens were cyanided for varying lengths of time (15 minutes to 1 hour) at 1500 degrees Fahr., quenched in water and reheated to 212 degrees Fahr. for 1 hour. The specimens were tested for percentage reduction of area. Notwithstanding the drawing treatment, marked brittleness is still in evidence, in that the reduction of area remains in the neighborhood of 4 per cent.

The foregoing data indicates that a piece of steel which has been cyanided and quenched in water will snap readily when subjected to stress. When the case is removed the same metal possesses ductility. Therefore, the brittleness in the core is apparent and only apparent. The visible lack of ductility in the presence of the hard superimposed shell is occasioned by the intertwining

of the grains in the case and core. In the region where carburization (or nitrodizing, if the term is more appropriate) ceases, the hard and soft crystals are so mutually involved or enfolded that when the outer brittle layer is ruptured, failure is rapidly transmitted through the interior. Briefly, the brittle nitrogenous case acts as a seat of rupture. When the "case" is ground away the point of origin or the region of incipient breakage is removed. When the "case-free" metal is subsequently subjected to stress, no embrittlement is in evidence.

Conclusions

(1) Water quenched parts, cyanided at 1500 degrees Fahr., are brittle.

(2) Brittleness in the core is apparent and not real.

(3) The core possesses ductility.

(4) Breakage of cyanided products is developed by the extreme brittleness of the case, which gives rise to an incipient crack when sudden shock or a steady load is applied.

(5) When inchoate rupture is once effected, breakage is rapidly transmitted through the core, because the crystals of the hard surface and tough interior are mutually involved or intertwined. Breakage is somewhat analogous to a detail fracture, in that the hair line cracks which develop in the case act as seats of rupture.

(6) The brittleness of cyanided parts is not due to the strained condition of the metal.

(7) Oil-quenched parts cyanided at 1500 degrees Fahr. do not possess the marked brittleness which is characteristic of water immersion. Oil-quenched specimens possess a satisfactory degree of hardness.

The Authors

Victor E. Hillman has been associated with the Crompton and Knowles Loom Works as director of chemical and metallurgical research for the past nine years. He received his chemical engineering education at Notre Dame University and his early metallurgical training with the United States Steel Corporation. During the war he was affiliated with Savage Arms Corporation as chief of the metallurgical staff. He is the author of many articles pertaining to iron and steel and in-

dustrial problems which have been published in various industrial magazines.

He is honorary president of the Holy Cross Scientific Society, Holy Cross College, Worcester, Massachusetts, and president of the Worcester City Council.

V. E. HILLMAN

E. D. CLARK

Mr. Hillman is a member of the American Society for Steel Treating, American Chemical Society, American Institute of Mining and Metallurgical Engineers and American Foundrymen's Association, and Massachusetts Bar.

EARL D. CLARK has been affiliated with the Crompton and Knowles Loom Works research staff for the past eight years as chief of the metallurgical division. He received his education at Worcester Academy and Massachusetts College of Chemistry. He obtained his early metallurgical training while associated with the Wyman and Gordon Company of Worcester, Massachusetts. Mr. Clark is Chairman of the Worcester Chapter of the American Society for Steel Treating.

DISCUSSION

Written Discussion: By V. O. Homerberg, Cambridge, Mass.

Woodvine, in his paper "The Behavior of Case-Hardened Parts Under Fatigue Stresses" and published in the Carnegie Scholarship Memoirs of the British Iron and Steel Institute, Vol. XIII, 1924, obtained results similar to those of the authors. Specimens of a plain carbon steel were carburized for eight hours as measured from the time of charging, refined, then water hardened and tested. Both case and core together, and the case alone in the

refined and hardened condition broke without any elongation or reduction of area. The elastic limits of the case alone and of the case and core together in the hardened condition were found to have practically the same values. Similar results were obtained with a 3 per cent and a 5 per cent nickel steel.

Although Woodvine does not state the nature of the carburizing compound it is doubtful if any iron nitride is produced in the carburizing.

The present paper verifies the observations as to tensile tests on case hardened parts by Woodvine.

It is difficult to visualize the embrittling of the core by the effect of nitrogen from the cyanide when it is realized that the depth of penetration by using the gas, NH_3, for a considerable length of time is not great. It would seem as though the use of this gas should cause a more rapid and a deeper penetration than the use of cyanide.

The brittleness is undoubtedly due, as the authors state, to the extreme brittleness of the case. The concentration of the stresses at the terminal of the crack or failure would readily cause further rupture of the material so as to make the core appear brittle.

Exception is to be taken to the statement that a crystalline fracture usually results in an intercrystalline failure. Intercrystalline cracks have been observed in only abnormal cases such as the hardening of steel from abnormally high temperatures, the embrittlement of boilers when subjected to the action of alkaline water for a long period of time and in the "season cracking" of brass and similar alloys. Any evidence of such an observation in the present investigation would be appreciated by those who are studying the mechanism of intercrystalline failures.

Written Discussion: By S. P. Rockwell, Hartford, Conn.

Tis paper is the first coming to my at'ention in which physical tests of accuracy have been made. I regret that impact tests were not made and that analysis for nitrogen was neglected. There seems to be no doubt that cyanided steel increases in nitrogen. Brophy and Leiter, A. S. S. T. Vol. I, No. 6. d'Arcambal, A. S. S. T. Vol. II, No. 12. There further seems to be no doubt that nitrogen is a harmful element to introduce into steel in quantity. Vanick, A. S. S. T. Vol. IV, No. 1.

The question arises, is the effect of nitrogen introduced by cyanide the same in its effect on steel as that introduced by ammonia? Brophy based his brittleness idea from the bending of annealed cyanided wire $\frac{1}{16}$ inch in diameter of which the cyanide case had been removed.

Government impact tests on cyanided versus lead hardened gun parts in 1919 with and without removal of case showed a decided but erratic brittleness due to cyanide.

In both the above cases a doubt of accuracy exists as no data is given whether or not the cyanided case was entirely removed. The work by Hillman and Clark seems to have eliminated these features.

Oral Discussion

W. J. MERTEN: Mr. Chairman, we have done some work on the cyaniding of various grades of steels, particularly high carbon steels, in which this

embrittling phenomenon was observed. When cyanided at a high enough temperature to introduce a rather coarsening of the grain on the surface the embrittling was very pronounced. When we did the cyaniding at temperatures around 700 degrees Cent. ranging from 690 to 710 degrees Cent. and surface hardness only was obtained, the ductility was surprisingly good. We experimented with drill rod of one and one-quarter per cent carbon steel and were able to bend the rod through 180 degrees. Equally well did we bring about a ductility in the lower carbon steels producing a ductility which was entirely lacking when cyaniding at higher temperatures.

C. A. LAMPARD: We have made quite a lot of experiments along these lines in case hardening with cyanide of high phosphorus steels. Now our conclusion is that it is a fact that this type of steel becomes brittle. But what are we going to do about it? We have conducted this test very thoroughly and are now running a low phosphorus steel on our screw machines for some classes of work. It is quite a problem in itself, that is to get a smooth piece of product. We have had to come to a low phosphorus steel to meet the requirements which we were after in cyanide casings, to give ductility. We have tried low temperature cyaniding, but we do not get the hardness, and we still run into some brittleness. So we have changed over to a low phosphorus steel of about 0.15 per cent carbon and this has eliminated a great deal of our trouble.

V. E. HILLMAN: In the case of low carbon steel with low sulphur and phosphorus, I do not think that you will obtain the same production on your automatics, in fact, I know you will not. We have overcome this brittleness in a large measure by quenching in oil. Cyaniding at best is only superficial, it is only skin hardness. We find that by quenching in oil we obtain a degree of hardness which is sufficient to withstand abrasion in the majority of parts, and the slight increase in hardness which you obtain by virtue of water quenching does not appear to be worth the hazards which you are likely to encounter by the brittleness which is induced in the metal.

W. J. MERTEN: May I ask the speaker what he is going to do with all the oil that he is going to spoil as a quenching medium when quenching cyanide heated parts in oil?

V. E. HILLMAN: I will admit that certain kinds of oil become gummy and deteriorate by virtue of quenching material therein which has been cyanided, but I understand there are reputable oil manufacturers who put an oil on the market which is not affected by cyanide quenching.

C. A. LAMPARD: May I say a word along those lines on oil-quenching of cyanide parts? If course, you all know if we oil quench directly from the cyanide bath we have a very gummy mess, and it means a lot of work to clean it up. What we are doing is to dump the work from the cyanide pots into cooling pans and after cooling, wash the cyanide off with hot water and reheat and quench. Of course, we do not get a case nearly as hard as if we quenched right directly in water.

We have a proposition on padlock shackles where we must satisfy the trade as to hardness. These requirements are very severe as this class of product must be so hard that it cannot be cut or filed. The only way we can

(*Continued on Page 998*)

GRAPHITIZATION AT CONSTANT TEMPERATURE BELOW THE CRITICAL POINT

A Contribution to the Subject of Graphitization

By H. A. Schwartz and H. H. Johnson

Abstract

This paper is a brief sequel to an earlier paper, "Graphitization at Constant Temperature", by one of the authors. Evidence is furnished that the mechanism of the reaction, in its earlier stages at least, is identical above and below the critical point. It is further shown that the apparent permanence of the metastable system at atmospheric temperatures is not inconsistent with the conception that graphitization proceeds at any temperature, no matter how low.

The mechanism of the later stages of the reaction requires further study, as the evidence now available, for publication, is not sufficient to decide between two alternatives.

Introduction

At the 1925 meeting, one of the present authors presented a paper[1] outlining the application of mathematical analysis to the data of graphitization, together with certain conclusions regarding the probable mechanism of the reaction in the light of this method of attack. This publication concerned itself primarily with the reaction at temperatures above A_1, and it is our present purpose to report further results dealing primarily with the conditions at lower temperatures.

In the interest of brevity, the reader is referred to the former paper for an exposition of the fundamental mathematics, which will not be repeated here.

The following discussion is believed generally applicable though certain special cases are known to us where there exists an abnormal temperature coefficient accompanied by a discontinuity of rate at A_1

Locus of the Graphitization Curve Below A_1

The positions of the first two points in Fig. 3 of the earlier

[1] "Graphitization at Constant Temperature," H. A. Schwartz. Transactions of American Society for Steel Treating, Vol. IX, June, page 883, 1926.

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. Of the authors, H. A. Schwartz is manager of research, and H. H. Johnson is research chemist, National Malleable and Steel Castings Co., Cleveland.

paper suggest that the postulated form of equation—

$$c = at^{1.5}$$

may be in error in the direction of too low an exponent of t. A relation of the form—

$$c = at^{2}$$

seems to be quite possible, which would indicate an interface reaction.

In order to check up this possibility, as well as to secure a better knowledge of the temperature coefficient of the reaction a further study has been undertaken.

We determined anew a few points on the graphitization curves, at two different temperatures, of a hard iron similar to "A" of the preceding study, which we may here designate "C", and also availed ourselves of a series of determinations in this range of iron "B", made some years ago in this laboratory by G. M. Guiler and (Mrs.) Anna Hird.

In Fig. 1 we have plotted the observations to logarithmic scales for time and per cent of graphite. It is very plain that if we assume the locus of the several series to be straight lines, as they must be if the graphite formed is proportional to any power of time, then they conform more closely to the first assumption than any other. Only the data previously reported would correspond better with a higher power.

Our postulate as to the similarity of the locii of the graphitizing curves at temperatures above and below A_1 is thus supported at least so far as the early stages are concerned.

From what was said in explanation of Fig. 5 of the earlier publication, the graphitization curve represents in its early stages the sum of the two curves of the same formula, but in which the values of "a" differ. One represents the destruction of the eutectoid cementite, the other that of the primary cementite. The former is observed to be the more rapid; hence, the relation—

$$c = at^{1.5}$$

must end when spheres from which the pearlite has been removed, "interfere" as explained in the earlier paper.

The course of the second stage of the sigmoid curve remains to be explained.

The last logarithmic segment of the graphitization curve

above A_1, see Fig. 2 of the earlier paper, has an intercept on the carbon concentration axis, determined by the difference in carbon solubility in the two systems, which is negligibly small below A_1.

The corresponding segment of the curve now under consideration will, therefore, have the equation—

$$K = 0$$

and hence, disappears.

We may, therefore, interpret the second part of our locus, whose formula is logarithmic, as equivalent to the second and

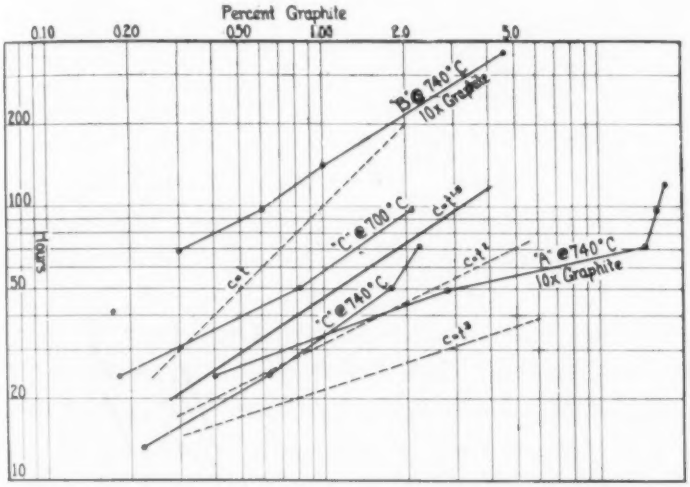


Fig. 1—Graphitization Curve Below A_1. H. A. Schwartz.

third segments of the curve, at high temperature, and hence as the empiric form of a complex transition condition.

Alternatively, we may regard it as the equation of a unimolecular reaction in situ, or we may seek an equation of some other form, agreeing equally well with the data.

An equation of the form—

$$K = B\ (T_o - T)^3$$

in which T_o is the time to attain equilibrium, would point to a reaction at the cementite ferrite interface, and might occur if this interface became so small that the solution of cementite would become less rapid than the migration of carbon.

By suitable selection of the constants, an equation of this form could be given a locus experimentally indistinguishable from the logarithmic.

Thermal Coefficient of Graphitization Rate Below A_1

In the former paper it was stated that this thermal coefficient was small. The data then available as a basis for this conclusion, were the results of experimentation on specimens graphitized to equilibrium at 1650 degrees Fahr. (900 degrees Cent.), whose reaction rates were plotted during the subsequent completion of the reaction at varying temperatures below A_1. It now appears that this reasoning may not be admissible. We have available data for the determination of the reaction velocity of a given iron, ("C"), in the initial stages at 1292 and 1472 degrees Fahr. (700 and 800 degrees Cent.).

In 24 hours this metal formed 0.62 per cent graphite at 1360 degrees Fahr. (740 degrees Cent., and 0.18 per cent graphite at 1292 degrees Fahr. (700 degrees Cent). From these figures we may calculate the thermal coefficient, and find that an increase of 10 degrees Cent. multiplies the reaction velocity by 1.229, a result in surprising accord with the coefficient at higher temperatures.

It has always been a question whether there is any limiting temperature below which graphitization is impossible. If we extrapolate downward to 20 degrees Cent., we find that this iron should at room temperature produce in twenty years, something under 0.0001 per cent graphite. Examination of a number of samples of hard iron preserved at atmospheric temperature from eighteen to thirty years has so far failed to disclose any temper carbon. It follows that there is no reason to believe that graphitization cannot occur at any temperature, the data given being amply sufficient to support the conclusion that the velocity, at ordinary temperatures, would be so slight as to preclude the detection of the temper carbon formed in a single life time.

We would be most anxious to examine any white cast irons of suitable composition, known to be one or two hundred years old.

Change of Reaction Rate at A_1

In the previous paper it was brought out that the reaction rates at A_1 in alpha and gamma iron were very similar. The evidence was derived from data as to reaction velocities below A_1 when graphitization was nearly complete.

On the basis of the preceding section we may extrapolate

upward from our data at 1360 degrees Fahr. (740 degrees Cent.), and determine the reaction velocity of material "A" at 1400 degrees Fahr. (760 degrees Cent.) in alpha iron, and downward from the data at 1436 and 1652 degrees Fahr. (780 and 900 degrees Cent.), to determine the velocity in gamma iron at 1400 degrees Fahr. (760 degrees Cent.).

The coefficient a in the formula—

$$c = at^{1.5}$$

measuring c in per cent graphite and t in hours, so calculated is 0.0026 in gamma iron and 0.0024 in alpha iron, confirming the conclusion that there is no marked change in reaction velocity, and hence in mechanism, on passing through the transformation point.

Conclusion

It is concluded that,

1. At least in the initial stages, the relation of graphite formation and time are the same above and below the critical point.

2. The thermal coefficient of the reaction velocity is of the same order of magnitude just above and just below the critical point.

3. The reaction velocity suffers no demonstrable discontinuity at the critical point.

4. No reason exists for assuming that graphitization does not progress at all temperatures, no matter how low.

5. The mechanism of the later stages of graphitization at constant temperatures below A_1 requires further study.

The Authors

H. A. Schwartz was born in Oldham County, Kentucky, in 1880, graduated from Rose Polytechnic Institute in 1901, receiving the degree of Bachelor of Science; in 1903 he received the degree of Master of Science and the degree of Mechanical Engineer in 1905. Was instructor at Rose Polytechnic Institute in 1901 and 1902. From 1902 to 1920 at Indianapolis Works of the National Malleable Castings Company employed as draftsman, chemist, metallurgist, and assistant superintendent. In 1918 was metallurgical engineer for entire

corporation, office at Indianapolis. From 1920 to date has been manager of research at the National Malleable and Steel Castings Company, Cleveland. Member of American Society for Steel Treating, being chairman of the Cleveland chapter, 1924-25 and 1925-26; American Institute of Mining and Metallurgical Engineers; American Foundrymen's Association; American Society for Testing Materials (Committee E4), Society of Auto-

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HAROLD H. JOHNSON was born at Brazil, Indiana, in 1902. Graduate of Rose Polytechnic Institute, B. S., 1923, M. S., 1925.

After a brief time in experimental work with the Sinclair Refining Company at Whiting, entered the employment of the National Malleable and Steel Castings Company at Cleveland, as research assistant, the position which he now holds.

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—Part X[1]

By H. B. Knowlton

Abstract

This article gives a discussion of the properties and uses of alloy steels other than tool steels in general, and a more detailed discussion of the various types of nickel steels.

Alloy Structural Steels

In the previous discussion of low and medium carbon steels and their heat treatment, only the plain carbon steels were considered. During the past quarter of a century there has been a rapid growth in the use of alloy steels of low and medium carbon contents for structural parts. (The term "structural" is here used in the broad sense as applied to automotive, railway, and machinery parts, not as sometimes used to apply only to building and bridge structures.) The development of the automobile has been perhaps the largest factor in the development of alloy structural steels.

Definitions

It is difficult to give a definition which will include all alloy steels and exclude all plain carbon steels. The steels which are the most simple in composition are commonly called "plain carbon steels". It is sometimes stated that the properties of these steels depend entirely upon the carbon and the iron forming the steel.

[1]The first installment of this series of articles appeared in the March, 1925, issue of Transactions, the second installment appeared in the June, 1925, issue, the third installment appeared in the October, 1925, issue, the fourth installment appeared in the January, 1926, issue, the fifth installment appeared in the April, 1926, issue, the sixth installment appeared in the May, 1926, issue, the seventh installment appeared in the June, 1926, issue, the eighth installment appeared in the August, 1926, issue and the ninth installment appeared in the October, 1926, issue.

The author, H. B. Knowlton, member of the Milwaukee Chapter of the Society, is instructor in metallurgy, Milwaukee Vocational School, Milwaukee, Wisconsin.

This is hardly correct as all commercial steels contain other elements besides iron and carbon which have their influence upon the properties of the finished steel. The most important elements other than iron and carbon found in plain carbon steels are manganese, silicon, sulphur and phosphorus. In the better grades of plain carbon structural steels, the content of these elements is usually held between the following limits:

	Per Cent
Manganese	0.30—0.80
Silicon	0.10—0.35
Sulphur	less than 0.05
Phosphorus	less than 0.045

Manganese is added to the steel as a cleaner. One of its functions is to combine with oxygen and work up into the slag thus removing oxygen and oxides from the steel. The small amount of manganese that is left in the steel raises the tensile strength somewhat. Manganese also combines with the sulphur forming a less objectionable compound than the iron suphide which would be formed in the absence of manganese. Nevertheless, as long as the manganese content is not higher than the above figures, the steel is not considered an "alloy" steel. Similarly in the acid steel making process, silicon is added as a cleaner, and while its influence is beneficial the steel produced is not classed as an alloy steel as long as the content of silicon remaining in the steel is small. Sulphur and phosphorus are objectionable impurities causing brittleness. In no case should a steel high in sulphur or phosphorus be called an alloy steel even though the sulphur is intentionally added as is sometimes done in the manufacture of screw stock. A steel which is a little higher in silicon or manganese than the above limits is not necessarily an alloy steel, unless the alloying elements are added intentionally to produce properties superior to those obtainable in a plain carbon steel. For example a cheap low carbon steel running a little high in both sulphur and manganese is not superior to a steel lower in these elements, consequently it is not called an alloy steel.

An alloy steel may be described as one whose useful physical properties have been considerably improved by the addition of some element other than iron and carbon, in a larger proportion than found in the ordinary plain carbon steel. It is necessary that the addition be intentional and that the properties be improved to

a commercial degree in order that the steel may be considered an alloy steel. This definition would include steels in which the silicon or manganese content is considerably increased or ones to which elements not found in plain carbon steel are added.

Some writers prefer to divide the alloy steels into two classes: (a) the alloy steels which contain in the finished steel one or more elements other than carbon, in sufficient proportion to materially improve the properties of the steel; (b) alloy treated steels which are steels to which one or more elements have been added for curative purposes, but which do not contain enough of the added element in the finished steel to materially change its properties. The steels in the latter classification may be superior to plain carbon steels due to better deoxidation and cleaning produced by the added element.

General Properties and Uses of Alloy Steels

The properties of steel may be varied in so many ways by the additions of alloys that it is difficult to give any generalizations with regard to the effect of alloys. Also the effect of any one element may vary considerably depending upon the amount of the element contained in the steel. For example the addition of manganese up to a certain amount may increase the strength of steel without proportionately decreasing the toughness. Above this there is a quantity of manganese which makes the steel very brittle. A still higher quantity of manganese may produce a tough alloy. The following may be listed as some of the effects produced by the addition of alloying elements:

1. The critical points may be either raised or lowered
2. The tensile strength may be increased
3. The toughness may be increased
4. The steel may become more brittle
5. The speed of quenching necessary to produce maximum hardness may be decreased.
6. The steel may be made more resistant to heat or corrosion
7. The magnetic properties may be changed
8. The coefficient of expansion with increase of temperature may be changed.

Five General Types of Alloy Steels

The alloy steels may be divided into five general classes

depending upon the types of structure produced by slow cooling from above the upper critical point. Usually two or three of these types may be produced by the addition of varying amounts of the same alloying elements.

1. *Low alloy or pearlitic alloy steels*

Nearly all of the steels which contain only a small amount of the alloying element fall in the pearlitic class. That is after low cooling from above the upper critical point the structure is at least partly pearlitic, just as it is in the case of the plain carbon steels. While the low alloy steels are generally superior to the plain carbon steels they are similar to the simple or plain carbon steels in every respect. The critical points may occur at different temperatures but the transformations occurring at the critical points are the same. The pearlitic alloy steels are subject to the same annealing hardening and tempering treatments as the simple steels of the same carbon contents, although the temperatures of heating and the method of cooling may be different. In general the effect of the alloying elements is to increase the strength, increase the toughness, increase the hardening power, or to produce some combination of these effects.

2. *Martensitic alloy steels*

In the case of some of the alloy steels there is a range of composition of the alloying element and the carbon which produces in the slowly cooled condition a martensitic structure. This condition may be produced by raising the content of either the carbon or the alloying element slightly above the limit for pearlitic steels. In general, alloys of this type are likely to be hard and brittle, although the degree of hardness and brittleness will vary with the carbon content. Consequently, there are not many steels in this class for which a practical use has been found.

3. *High alloy austenitic steels*

An increase of the content of the alloying element above the martensitic range will produce steels which are austenitic even after slow cooling. That is, they exist in the same condition after cooling that all steels are in white heated above the upper critical point. All of the constituents of the steel are in a solid solution. Such steels are, in the main, fairly tough (some are very tough);

they are more resistant to heat and corrosion; if completely austenitic, they are nonmagnetic. Some of the austenitic steels are quite resistant to wear but in the main the austenitic steels are not as hard as the martensitic steels or the hardened pearlitic steels. A truly austenitic steel cannot be hardened by any quenching method with the possible exception of quenching in liquid air. On the other hand some of the fairly high alloy steels which are not entirely austenitic after low cooling may be made austenitic by quenching.

4. *High alloy cementitic steels*

High percentages of chromium, vanadium, molybdenum and tungsten do not produce steels having an austenitic structure after slow cooling from above the critical point. The structure so produced is described as cementitic. The distinguishing characteristic of this type of structure consists of numerous particles of cementite imbedded in the matrix or background of the structure. The cementite is composed of carbides of iron and of the alloying elements and sometimes of compounds of the alloying element with iron. Some of the high alloy tool steels fall in the cementitic class.

5. *High alloy graphitic steels*

Steels containing more than about 5 per cent of silicon in absence of other alloys would contain at least some of the carbon in the form of free graphite. Such steels are not used commercially as free graphite decreases both the strength and the toughness of the alloy.

Nickel Steels

The use of nickel as an alloying element in steel dates back about 40 years, but as is the case with other alloying elements, there has been a rapid development in the study of nickel iron alloys and the use of nickel steels in the past ten or twenty years. The variation of the nickel content in useful nickel steels is greater than that of any other alloying element. Camp and Francis[2] state that the composition of useful nickel steels varies from 0.5 per cent to 46.0 per cent nickel. Iron-nickel or as they are sometimes called "ferro-nickel" alloys containing even higher nickel have been found to have some very useful magnetic properties. For

[2]Making, Shaping and Treating of Steel.

example "Permalloy" which contains about 78.2 per cent nickel, 21.3 per cent iron, 0.04 per cent carbon has a high magnetic permeability.

General Effects of Nickel

Nickel forms a solid solution with iron but does not readily form a compound with carbon. The nickel in nickel steel, like most of the other alloying elements in alloy steels, cannot be seen as a separate constituent, when a polished and etched specimen of the steel is examined with a microscope. It is present as a part of the ferrite in the low nickel steels, and as a part of the martensite and austenite in the steels of medium and high nickel content. It does not form a part of the cementite as it does not combine with carbon. It does tend to produce a finer grain size and a finer and more desirable structure in the pearlitic areas of the low and medium carbon low nickel steels. One of the most important effects of nickel is that of lowering the critical points both on heating and cooling. With a nickel content of 30 per cent or more the critical point on cooling (Ar point) is depressed below ordinary room temperature. Consequently such steels are always above their critical points and have an austenitic structure. The exact position of the Ar points depends on the quantity of both carbon and nickel, and on the temperature to which the steel is heated and the speed with which it is cooled as well. Even when the nickel content is not high enough to lower the critical point below room temperature, the nickel retards the transformation of austenite into pearlite as the steel cools below the critical point. For this reason the nickel steels which are subject to hardening and heat treating, may be given a slower quench than that necessary to produce the desired results with the corresponding plain carbon steels. Nickel unlike some of the other alloying elements cannot be used as a deoxidizer or cleaner in manufacturing steel.

Three General Types of Nickel Steels

Like some of the other alloy steels, the nickel steels are frequently divided into three general types depending upon the structure which is produced by slow cooling from above the critical point. These are shown most clearly by Guillet's diagram (Fig. 1). Each of the vertical lines represent a different per cent of carbon while the horizontal lines represent the nickel content. To find the

class or type to which any particular steel belongs find the intersection of the horizontal and vertical lines corresponding to the nickel and carbon content of that steel, and note in which of the three large areas the point of intersection of the two lines falls. The boundaries between the three zones are marked by the slanted

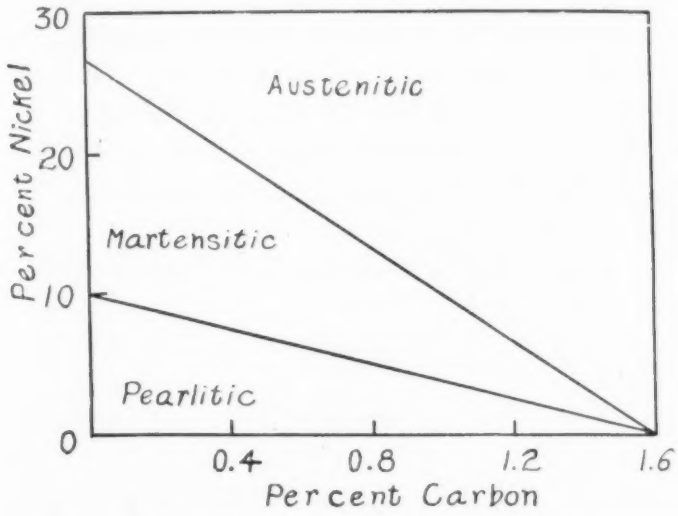


Fig. 1—Nickel Steel. Constitutional Diagram. (Guillet.)

lines. All of the steels falling in the upper zone are austenitic, those in the middle zone are martensitic, and those in the lower zone are pearlitic. The boundaries are not really sharp lines but rather broad bands or transition zones. Steels which fall in the transition zones have mixed structures after slow cooling.

Pearlitic Nickel Steels

From the tonnage production standpoint, the pearlitic nickel steels are by far the most important of the three general types of nickel steel. This class includes low carbon steels with nickel contents up to 8-10 per cent. As the carbon content is increased the maximum limit for nickel content is decreased. Thus the maximum limit for nickel in a 0.80 per cent carbon steel is about 5 per cent. In commercial practice the nickel in the pearlitic steels is held below 5 per cent as steels with higher nickel content are more difficult to forge. The most common classes of pearlitic nickel steels contain from 0.5-3.5 nickel.

Effect of Nickel in Pearlitic Steels

The following may be listed as some of the effects of nickel in steels containing up to 5 per cent of the alloying element.

1. Nickel increases the strength of annealed or untreated steel without decreasing the ductility or toughness correspondingly. In this respect nickel is quite different from carbon for, while increasing the carbon content, it raises the tensile strength, it also lowers the ductility at the same time. The A. S. S. T. Handbook quotes the following data from Abbot concerning the effect of nickel up to 8 per cent upon the physical properties of annealed steel.

0.01 per cent of nickel increases the elastic limit 40 pounds per square inch.

0.01 per cent of nickel increases the tensile strength 42 pounds per square inch.

0.01 per cent of nickel increases the reduction of area 0.005 per cent.

0.01 per cent of nickel decreases the elongation 0.01 per cent.

2. Nickel may be said to increase either the strength or the toughness of heat treated steels, depending upon the heat treatment given. Thus if a 3.5 per cent nickel steel is compared with a similar plain carbon steel having the same figures for elongation or reduction of area, it will be found that the nickel steel is the stronger. Similarly if the heat treatments are such that the two steels have the same tensile strength, it will be found that the nickel steel is the tougher. Table I copied from Circular of the Bureau of Standards No. 100 will bear out this point.

It is also interesting to note in Table I that in the cases where the elongation is the same for both the carbon and the nickel steels that the reduction of area of the nickel steel is greater than that of the carbon steel. Some metallurgists believe that the reduction of area is a better criterion for judging the toughness and servicability of steel than the elongation.

3. Nickel lowers the critical points and therefore the temperatures of quenching for hardening or heat treating. This means, of course, that the dangers of scaling and warping are somewhat diminished. Lower temperatures also mean lower fuel consumption and less damage to the furnaces.

4. The presence of nickel lowers the speed of quenching neces-

sary to produce a given amount of hardening or strengthening. As may be seen from Table I a 0.40 per cent carbon 3.5 per cent nickel steel may be quenched in oil and still produce higher tensile strength, yield point and reduction of area than could be produced by water quenching a similar carbon steel. This property

Table I

Comparison of Tensile Properties of 0.40 per cent Carbon Steel with and without 3.5 per cent Nickel.

Material	Yield Point Lbs/in²	Tensile Strength Lbs/in²	Elongation in 2 inches Per Cent	Reduction of Area. Per Cent
0 Ni; quenched 1450°F. in water and tempered 1300°F.	53,000	90,000	25	62.5
3.5 Ni; quenched 1490°F. in water and tempered 1260°F.	83,000	108,000	25	66
0 Ni; quenched 1450°F. in water and tempered 940°F.	86,000	123,000	20	51
3.5 Ni; quenched 1400°F. in oil and tempered 935°F.	107,000	124,000	20	57
0 Ni; quenched 1450°F. in water and tempered 750°F.	117,000	154,000	15	40
3.5 Ni; quenched 1400°F. in oil and tempered 725°F.	158,000	168,000	15	48

of nickel steel is desirable, for the slower the quenching speed the less are the dangers of warping, and distortion due to quenching. At the same time it should be said that the 3.5 per cent nickel steels are not made as brittle by water quenching as are some of the other alloy steels.

Some Common Nickel Steels and their Uses

0.5-1.5 per cent Nickel Steels

There are several steels in this class which are used for case hardening. The average carbon content may be either 0.15 or 0.20 per cent. They are sometimes designated as 2115 or 2120 depending upon the carbon content. (This follows the general plan of the S. A. E. specification numbers. All numbers beginning with 2 are nickel steels. The second figure of the number tells the per cent of nickel while the last two figures give the average carbon content. Thus 2115 should be a 1 per cent nickel steel with an average carbon content of 0.15 while 2315 is a 3.5 per cent nickel steel containing 0.15 per cent carbon.)

These low nickel steels are cheaper than the 3.5 per cent nickel steels. It is claimed that they are superior to plain carbon steels for case hardening, as the core produced is tougher and the case is harder after an oil quench.

3.5 per cent Nickel Steel

By far the most popular of all of the forging and structural nickel steels are these containing about 3.5 per cent. The usual specifications permit a variation in the nickel content from 3.25-

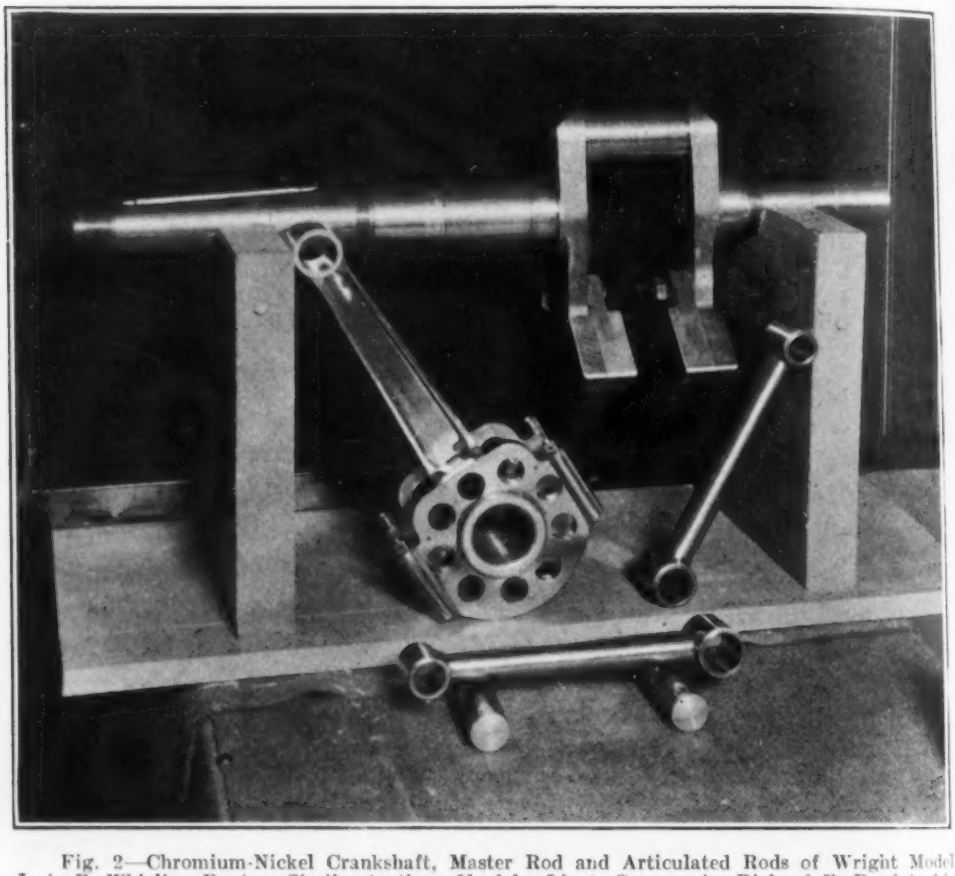


Fig. 2—Chromium-Nickel Crankshaft, Master Rod and Articulated Rods of Wright Model J. A. B. Whirling Engines Similar to those Used by Lieut. Commander Richard E. Byrd in his Flight over the North Pole. Composition: S. A. E. 3140.

3.75 per cent. These steels are made with carbon contents varying from 0.10-0.55 per cent depending upon the purpose for which the steel is to be used.

The 3.5 per cent nickel steels are used both in the heat treated and the untreated conditions. In the untreated condition they are used for many parts which cannot be safely heat treated on

account of their size or shape. The following may be given as some of the uses of untreated nickel steels.

Rivets: steel containing about 0.25 per cent carbon.

Bridge construction: steel containing about 0.30-0.40 per cent carbon.

Heavy forgings such as locomotive, engine and ordnance parts steel usually of medium carbon content.

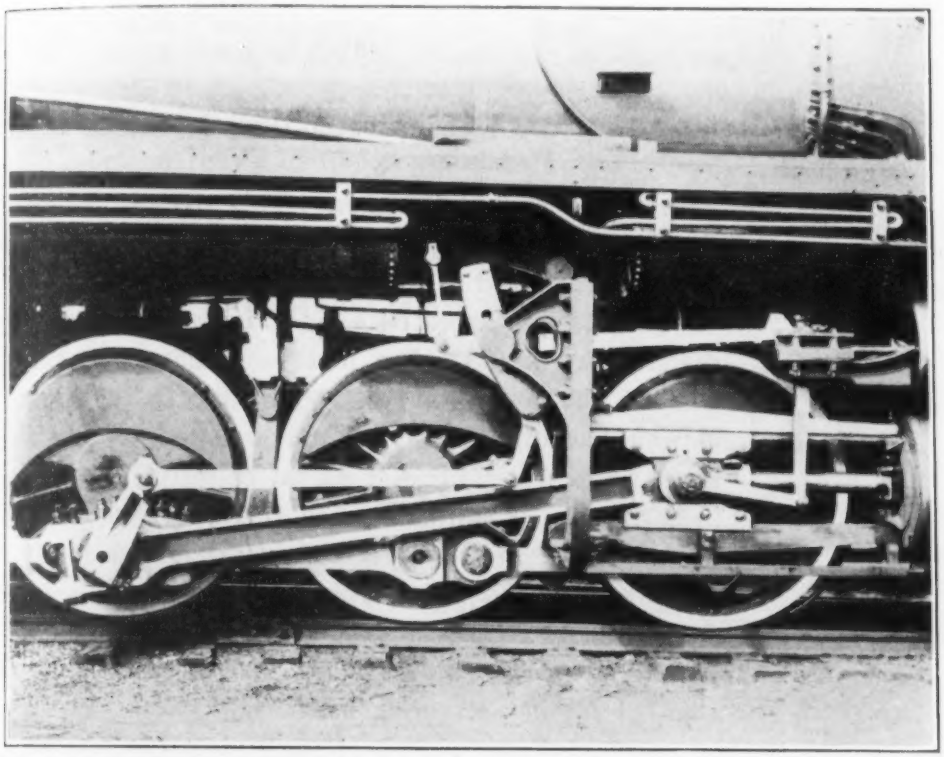


Fig. 3—Nickel Steel Connecting Rods Used on Type 5300 Mikado Locomotive made for the Canadian Pacific Railroad. Composition: 2 per cent Nickel, 0.38-0.42 per cent Carbon.

Bolts, studs, etc. requiring strength but which are not heat treated on account of the danger of scaling: cold drawn nickel steel with about 0.30 per cent carbon.

The effect of heat treatment upon the 3.5 per cent nickel steels is best shown by the following table taken from Circular 100 of the Bureau of Standards. (Table 43)

For more specific data concerning the physical properties produced by the different quenching and tempering treatments, the reader is referred to charts in the S. A. E. Handbook.

The following are some of the uses of the steels in the 3.5 per

TABLE 43.—*Range of Tensile Properties of Annealed and Heat-Treated 3½ Per Cent. Nickel Steel.* (*S. A. E. Handbook, Vol. 1, Sec. D.*)

S. A. E. Steel Number	Annealed			Heat-treated		
	Yield Point	Elongation in 2 inches	Reduction of Area	Yield Point	Elongation in 2 inches	Reduction of Area
	Lbs./in.²	Per Cent	Per Cent	Lbs./in.²	Per Cent	Per Cent
2315 ...	35,000-45,000	35-25	65-45	40,000- 80,000	35-15	65-40
2320 ...	40,000-50,000	30-20	65-40	50,000-125,000	25-10	65-40
2330 ...	40,000-50,000	30-20	60-40	60,000-130,000	25-10	60-30
2335 ...	45,000-55,000	25-15	55-35	65,000-160,000	25-10	55-25
2340 ...	55,000-65,000	25-15	50-30	70,000-200,000	25- 5	55-15

cent nickel series. They are classified according to the S. A. E. designations.

2315—0.10-0.20 per cent carbon. This steel is designed for case hardening. After such a treatment it has a tough core and a strong hard case.

2320—0.15-0.25 per cent carbon. This steel is not as satisfactory as 2315 for most case hardened parts because the core is not as tough, due to the higher carbon content. It is recommended principally for large parts which are not cooled rapidly by quenching. As the carbon content of the core is raised the critical point of the core is lowered nearer to that of the case, consequently the heat treatment becomes more difficult.

2330—0.25-0.35 per cent carbon. This steel is recommended for heat treated automotive parts. It may be quenched either in oil or water.

2340—0.35-0.40 per cent carbon.

2345—0.40-0.50 per cent carbon. For heat treated parts. Should be oil quenched. Probably not as much used as 2330. It is somewhat harder and less tough after similar treatments. It may be used for gears and other parts requiring some hardness.

2350—0.45-0.55 per cent carbon. For large gears which require a higher carbon content in order to produce the desired hardness.

Nickel Steel Castings

Before leaving the subject of the low nickel steels it should

be mentioned that nickel has been used quite successfully in improving the properties of steel castings both in the annealed and the heat treated conditions. McKnight[3] gives the following comparison between the properties of 3 per cent nickel steel castings and carbon steel castings, both with a carbon content of about 0.30-0.40 per cent and in the annealed condition.

	Elastic Limit Lbs/in²	Tensile Strength Lbs/in²	Elongation Per Cent	Reduction of Area Per Cent
High Carbon Steel ..	30,000 to 40,000	65,000 to 70,000	15-20	25-30
3 per cent Nickel ...	55,000 to 65,000	85,000 to 90,000	23-28	33-38

Nickel-chromium and nickel-manganese steel castings also were reported as very good.

Heat Treatment of 3.50 per cent nickel steels

In the heat treatment of the 3.5 per cent nickel steel the same principles apply as in the case of the plain carbon steels of similar carbon contents except that the quenching temperatures are in the main lower and sometimes oil quenching should be used in the place of water quenching. Also the tempering temperatures necessary to produce certain properties will, of course, be different.

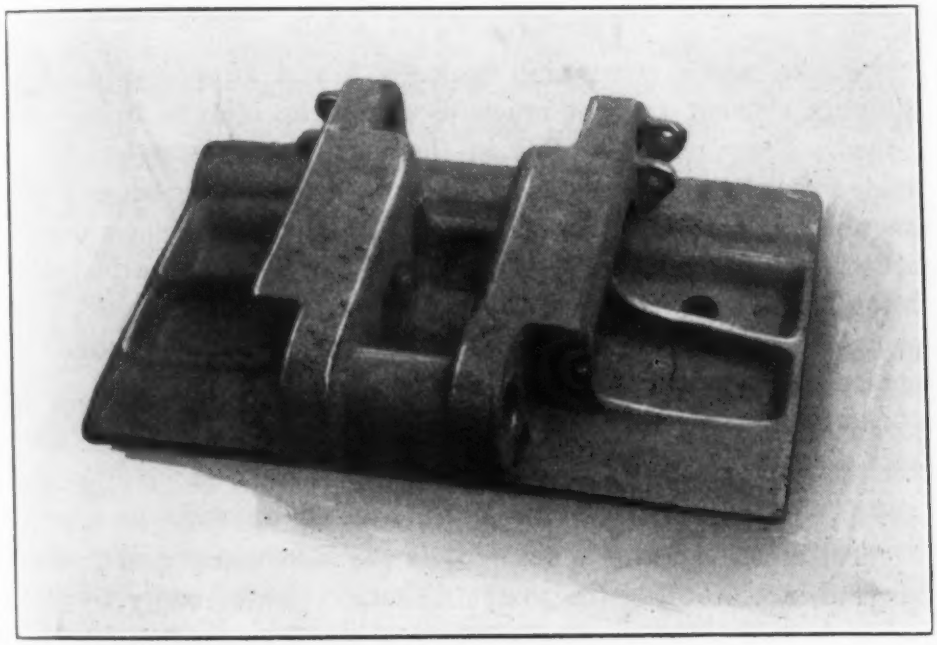


Fig. 4—Chromium-Nickel Cast Steel Tractor Shoe.

[3]International Nickel Co., Circular No. 4.

If the initial structure of the nickel steels is coarse-grained due to high forging temperatures a normalizing treatment may be necessary. This consists in heating to 1600-1750 degrees Fahr. followed by cooling freely in air.

A complete description of all of the commercial heat treatments of 3.5 per cent nickel steels cannot be attempted in this article. For detailed data with regard to heat treatments and the properties produced, reference is made to the data in Handbooks of the A. S. S. T. and the S. A. E. and the and the data sheets of the International Nickel Co.

5 per cent nickel steel

The 5 per cent nickel steels are not as much used as those previously mentioned. The S. A. E. gives a specification for a 5 per cent nickel steel with a carbon content of 0.17 per cent maximum. This is recommended for case hardened parts requiring exceptionally strong tough cores.

Medium Nickel Steels

Nickel steels containing between 8 and 20 per cent of the alloying element are not much used for the reasons before mentioned. They normally fall in the martensitic zone but can be made softer by quenching as this treatment tends to produce austenite which is not as hard a martensite. Camp and Francis mention a steel containing 13 per cent nickel and 0.55 per cent carbon which is too hard to be machined and which has a yield point of 134,000 pounds per square inch, a tensile strength of 195,000 pounds per square inch, and an elongation of 12 per cent in two inches. Some of the steels near the higher limits of the martensitic zone of Guillet's diagram are reported as rust resisting.

Austenitic or High Nickel Steels

The steels containing from 25-35 per cent nickel and 0.30-0.50 per cent carbon fall in the austenitic zone. Consequently they cannot be heat treated, as heat treating is usually considered. Heating and quenching may slightly affect the physical properties but the structure remains austenitic.

While these steels are not used to as great an extent as the lower nickel steels they have some interesting and useful properties. They are more resistant to rust and corrosion than plain carbon or low alloy steels. Steels containing from 20-30 per cent nickel are

nonmagnetic after slow cooling from the rolling temperature.

The steels containing from 25-38 per cent nickel are normally quite strong and tough. They may be rolled or forged and they are fairly machinable. The following table copied from Circular 100 of the U. S. Bureau of Standards gives their physical properties.

TABLE 45.—*Tensile Properties of High-Nickel Steels.*

Tensile Properties	25 to 28 Per Cent Nickel	30 to 35 Per Cent Nickel	35 to 38 Per Cent Nickel
Tensile strength ....lbs./in.^{2}..	85,000-92,000	85,000-95,000	100,000-115,000
Yield point .....do....	35,000-50,000	40,000-50,000	64,000- 78,000
Elongation in 2 inches per cent.	30-35	30-40	25-35
Reduction of area .....do...	50-60	40-60	50

One of the most interesting of the properties of the high nickel steels is the low coefficient of expansion with increase of temperature. Invar, an alloy containing 36 per cent of nickel has a linear expansion of one millionth of an inch per degree centigrade at ordinary temperatures. It is used for balance wheels of watches, pendulums of clocks, and for other parts where the elimination of expansion with temperature is of maximum importance. 46 per cent nickel steel is called platinite because it has the same coefficient of expansion as glass and plantinum. Its replaced platinum for the lead in wires of electric light bulbs. More recently a 38 per cent nickel cored wire incased in copper has been used for the same purpose. The two together produce the same coefficient of expansion as glass and, consequently, the wire does not crack the glass seal when it gets hot.

24-32 per cent nickel steels are used for electrical resistors. In general the high nickel steels are used on account of their resistance to corrosion, their low expansivity, or their magnetic, nonmagnetic or electrical properties. The use of the very high nickel-iron alloy on account of its magnetic permeability has already been mentioned. The French have used a 30 per cent nickel steel for some parts requiring strength and toughness, but use for that purpose alone is not common in this country.

References.

A. S. S. T. Handbook
S. A. E. Handbook
Camp & Francis:—Making Shaping and Treating of Steel
Bullens:—Steel and Its Heat Treatment
Bureau of Standards, Circular 100
Data sheets and technical articles: International Nickel Co.

Note: The use of nickel in connection with other alloying elements will be discussed in another article.

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

BASIC OPEN-HEARTH FORGING STEEL. By R. L. Cain. In *Forging-Stamping-Heat Treating*, November 1926, page 432.

The author in this article states the controlling factors to be observed such as character of charge, working of heat, tapping and ladle additions, teeming and metallurgy. He also calls attention to the general precautions which shoud be taken in the manufacture of basic open-hearth steel. The author expresses the hope that more attention will be paid to the effect which the charge has on the quality of the steel produced, (especially pig iron).

ON THE DURABILITY OF THE ALKALINE SOLUTION OF POTASSIUM FERRICYANIDE AS AN ETCHING REAGENT IN MICROSCOPY. By Takejiro Murakami and Kin'ichi Someya. *Kinzoku no Kenkyu*, Vol. 3, No. 5, 1926, pages 263-276.

The alkaline solution of potassium ferricyanide prepared by dissolving a suitable quantity of potassium ferricyanide and potassium hydroxide in water is very conveniently used as an etching reagent in the micro-examination of chromium, tungsten, high speed and molybdenum steels, and also the phosphides in steels and cast iron. The special advantage offered by this reagent, in which it differs from the sodium picrate solution is that its etching action is sufficiently rapid at ordinary temperatures. This reagent is not very stable if left for a long time, decomposition and the consequent deposition of ferric hydroxide gradually taking place, and this made the writers undertake a more detailed study of the various features of this change in connection with its etching strength. The conclusions arrived at are as follows:—

(a). When the concentration of both solutes is above 5 per cent, a good etching is easily obtained in less than 20 minutes at room temperature. (b). The decomposition is faster with a greater concentration of alkali. (c). It decomposes rapidly in direct sunlight, but very slowly in a diffused daylight, especially so when it is kept in a brown bottle. (d). The decomposition of alkali takes place rapidly at first and becomes asymptotic with the lapse of time, while that of ferricyanide is, on the whole, linear. It was also ascertained that in the decomposition the ferricyanide changes first into the aquo-prussi salt, which is next reduced to the aquo-prusso salt, and then this second salt changes into the ferrocyanide. (e). The change in the etching efficacy as regards time, differs from that of the alkali or the ferricyanide in that for all concentration it is greater after the lapse of a certain time, than just after its preparation, and the strength begins to decrease gradually. The phenomenon is attributed to the probable

formation in the course of the decomposition of an intermediate compound possessing a greater etching action than ferricyanide. (f). When kept at a place in a room not exposed to direct sunlight, the etching action continues to increase for the first 4 to 6 months, after which it decreases gradually. But even after one year, the etching strength of the reagent is not very different from that at the beginning of the test.

Abstracted by Dr. Kotaro Honda, Japan.

MOVING HEARTH FOR THE IMPROVEMENT OF LIQUID CAST IRON AND STEEL. By C. Irresberger, Salzburg. *Stahl und Eisen*, June 30, 1926, pages 869-872.

By agitating a cast iron bath a degasification and a deoxidation is attained. Further, a mixing up of all the components is attained and at the same time the graphite is dissolved and the sulphur is rendered harmless. The author describes the cupola furnace plant of the "Deutsche Industrie-Werke A.-G. in Spandau" with moving forehearth, working according to this method. The physical properties of the cast iron treated in this manner are: tensile strength 45,000 to 57,000 pounds per square inch, bending strength 71,000 to 85,000 pounds per square inch, deflection 0.6 inch and Brinell hardness 180 to 240. In proportion to the tensile strength the hardness is surprisingly low.

The cost of this method of manufacture is low.

Abstracted by Dr. Hans Pollack, Germany.

DETERMINATION OF OXYGEN IN STEEL. By P. Oberhoffer, Aachen. *Stahl und Eisen*, August 5, 1926, pages 1045-1049.

The author reports his latest improvements and modifications of working methods, as well as his experiences with the different methods. The last report was published in *Stahl und Eisen*, 1925, page 1555.

Hydrogen method: The apparatus was perfected; the influence of the test form was examined on a great number of tests. The method has proven valuable, within its hitherto limited range of application.

For high carbon iron alloys the method is useless, as there is an incomplete reduction of the oxygen when combined with iron and manganese in the absence of silicic acid. Silicic acid and the other difficultly reducible oxides are not determined by this method. The reduction of manganous oxide was proved again. Recently experiments were made in an effort to reduce the difficultly reducible oxides by increasing the temperature.

Hot extraction method: The apparatus was also perfected. The hot extraction method is capable of obtaining comparable results as to the deoxidizing conditions on complex-steels. It may generally be said that an oxygen containing steel has a narrow hardening range, a tendency toward hardening cracks and a poor malleability.

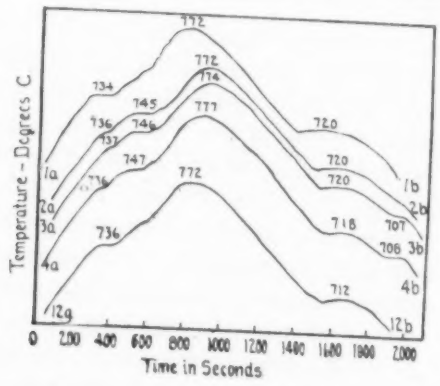
Abstracted by Dr. Hans Pollack, Germany.

PROOF OF THE HEAT CHANGE OF THE IRON-CARBON EUTECTIC. By R. Ruer, Aachen. *Stahl und Eisen*, July 8, 1926, pages 918-920.

In 1921 the author published a paper "On the knowledge of the iron-carbon alloys", Zeitschrift f. anorganische Chemie 117 (1921), p. 249, in which he produced the thermal proof of the iron-carbon eutectic. Anson

Hayes, H. E. Flanders and E. E. Moore contest the author's explanation of his experiments in their paper TRANSACTIONS, A. S. S. T., Vol. 5, 1924, page 183.

The author's investigations were made with a regulus consisting of purest electrolyte-iron and pure sugar-coal. With this button the author made heating and cooling curves as shown in the figure. After finishing the experiments the test-piece was examined and recognized as gray pig iron, containing 3.85 per cent carbon. Immediately after solidifying the regulus consists of austenite and graphite. On further cooling the transformations took place



after the metastable system. The critical point, appearing at 734 degrees Cent. (1353 degrees Fahr.) on the curve 1a corresponds to the transformation of the pearlite into austenite. In the following cooling, taking place very slow in comparison to the first, a great deal of the dissolved carbon is not separated as cementite but as graphite, accordingly the intensity of the critical point, corresponding to the pearlite transformation, on the following heating curve 2a decreases. Instead of it another critical point appears at 746 degrees Cent. (1375 degrees Fahr.) corresponding to the transformation of the graphite-ferrite eutectic of the stable system. The curves 3a and 4a represent the same procedure. This explanation is based upon the circumstances that both of these critical points is produced only, when the button had the gray iron solidification. White reguli showed a critical point only at 734 degrees Cent. (1353 degrees Fahr.). The essential result of the author's investigations is the fact that in pure iron-carbon alloys Ac_1 stable lies 12 degrees Cent. (21 degrees Fahr.) higher than Ac_1 metastable. These temperatures, 746 and 734 degres Cent. (1375 and 1353 degrees Fahr.) do not correspond to equilibrium temperatures but represent, as determined on heating curves, only the upper limits of these. To determine the equilibrium temperatures the author believed that the temperatures determined on the heating curves both lie about the same amount above the equilibrium temperatures. This belief appears most plausible as it is the same in both cases, the mutual dissolution of two sorts of crystals. It is admitted that the equilibrium-temperatures must differ about the same amount and as Ac_1 metastable has been determined at 721 degrees Cent. (1330 degrees Fahr. in pure iron-carbon alloys, that of Ac_1 stable must lie at 733 degrees Cent. (1351 degrees Fahr.).

The objections, raised against the author's interpretation by Hayes, Flanders and Moore are that the heatings and coolings were performed too rapidly and further that the regulus was only heated up to 777 degrees Cent. (1430 degrees Fahr.), while the formation of austenite from ferrite and pearlite does not take place below 780 degrees Cent. (1436 degrees Fahr.).

As far as the first opposition is concerned, the authors believe that the transformation temperature of the pearlite may be influenced by too rapid heating or cooling, as in this case incomplete equalization of concentration took place in the regulus. But that does not hold good for heating-curves, used by the author for his study. For the second objection, the authors rest upon Carpenter and Keeling, and Giolitti and Tavanti. In Carpenter and Keeling's diagram of the iron-carbon-alloys there are from 0.6 up to 4.5 per cent a large number of points in the range from 775 to 800 degrees Cent. (1427-1472 degrees Fahr.) which Hayes, Flanders and Moore regard as the segregation temperature of the stable eutectic (Ar_1 stable); but that is impossible as they put the A_1 stable point at 771 degrees Cent. (1420 degrees Fahr.) and as the heat effects in these cooling curves are very small, the existence of these points may be doubted; further it is said that Giolitti and Tavanti have proved that there is no formation of a solid solution from ferrite and carbon below 780 degrees Cent. (1436 degrees Fahr.); but the author could not find this proof in the mentioned paper.

Hayes, Flanders and Moore used the author's method in their investigation avoiding the sources of these faults; but the iron used for this investigation had 2.05 per cent of impurities. The heating curves of Hayes, Flanders and Moore correspond with those taken up by the author.

The difference between Ac_1 metastable and Ac_1 stable amounts to 15 degrees Cent. (27 degrees Fahr.) after Haynes, while the author stated such a one amounting to 12 degrees Cent. (21 degrees Fahr.) on a pure alloy. These results agree very well with each other. The equilibrium-temperatures, stated in the paper of Hayes, Flanders and Moore are too high. On pure iron-carbon alloys Bardenheuer stated the pearlite transformation at 740 degrees Cent. (1364 degrees Fahr.) and the equilibrium temperature lying below this temperature, was determined by the author and F. Goerens at 721 ± 3 degrees Cent. (1330 ± 5 degrees Fahr.) and that of the iron-graphite system at 733 ± 3 degrees Cent. (1351 ± 5 degrees Fahr.).

The difference in the absolute values of the equilibrium temperatures in the two papers must be attributed to the impure material used by Hayes, Flanders and Moore to their investigation.

Abstracted by Dr. Hans Pollack, Germany.

IMPROVEMENT OF THE HIGH QUALITY STEEL PRODUCTION BY APPLICATION OF FOUR-EDGED INGOTS TURNED ON THE LATHE. By P. Eyermann, Wien. *Stahl und Eisen*, August 12, 1926, pages 1083-1084.

In the manufacture of high quality steel, the ingots are examined thoroughly before further working, to remove surface defects and to make visible cracks, etc., in order that such ingots may be excluded from further manufacture. Machining of round ingots was generally done on the lathe; machin-

ing of four-edged ingots in this manner was impossible and by this it is quite logical that the four-edged ingots were displaced by the round ingots, although they surpass the last in quality and in the possibility of piling up, etc.

To pursue the advantages of the four-edged ingot, the author has designed a lathe, making it possible. This is briefly described. The economical production from this machine has been proven by comparing working experiments and by the experiences made in a working period of 1½ years. The result was the complete removal of the round ingots after the introduction of the turning of four-edged ingots. *Abstracted by Dr. Hans Pollack, Germany.*

THE ABILITY OF HIGH SPEED STEEL CUTTERS AND THEIR TESTING. By Dr.-Ing. F. Rapatz, Duesseldorf. Report of the Material-Committee of the Verein deutscher Eisenhüttenleute; *Stahl und Eisen*, August 19, 1926, pages 1109-1117.

This paper deals with the circumstances, influencing the cutting qualities of high speed steel. Questions, which do not belong to the metallurgical range, such as the form and the dimensions of the tool, the ratio of the feed to the depth of cut and the power consumption, are eliminated; only the effect of the hardening and of the hardening temperature, of the tempering of high speed steel, of the cutting speed and of the properties of the material being cut are closely discussed. This paper deals only with the conditions applicable to lathe-tools. In practice there is often too little attention paid to these four conditions (hardening, tempering, cutting speed and properties of the material being cut).

The tests were not carried out after the method of Taylor, but after the breakdown one.

Hardening Temperature and Method of Hardening. To obtain good results, high hardening temperatures have to be employed; the reason for the use of such temperatures lies in the fact that steels hardened at high temperature are more resistant against tempering and that in general the effect of a steel will be thé greater, the greater its resistance to tempering.

Cutting tests carried out in different works show the great dependency of the cutting effect from the hardening temperature.

The microstructure of a hardened high speed steel consists of a polyhedral matrix in which a greater or less quantity of carbides are embedded. In general the microstructure of best hardened high speed steel shall consist of great and distinct polyeders; small or indistinct polyeders or their complete absence indicate an insufficient hardening temperature. Micrographs show the influence of the hardening temperature on the formation of polyeders in high speed steel containing 14 or 18 per cent tungsten. Overheating takes place when the eutectic component begins to melt. The steel is best hardened when heated to a temperature just below the melting point of the austenite-comentite eutectic. This point depends upon the chemical composition and varies from 1270 to 1320 degrees Cent. (2318 to 2408 degrees Fahr.). By addition of cobalt, the best hardening temperature is increased up to 1320 degrees Cent. (2408 degrees Fahr.).

Of great importance is the influence of time, during which the steel is kept at the hardening temperature. Due to the low melting point of the austenite-

cementite eutectic, it is very dangerous to keep the steel for too long a time at the hardening temperature. The hardening may be carried out in the salt bath, the gas-fired muffle furnace or in the tempering forge.

Tempering of High Speed Steel. By tempering hardened high speed steel, the portion of austenite, being formed at the high temperature is transformed into austenite and by this the hardness of the tool increases. Not only the hardness is increased but also the toughness. Hohage stated *(Stahl and Eisen,* 1925, page 1126-30) that on soft materials the lathe tool is especially destroyed by the heating, while on hard materials the mechanical wear and tear comes more to the front. Tests have shown a considerable improvement of the cutting effect by tempering at 580 degrees Cent. (1076 degrees Fahr.). Tempering at lower temperatures has an unfavorable influence. The tempering temperature must be carefully measured. On steels, hardened from too low a temperature, the tempering must be avoided as the hardness of such steels decreases.

Influence of the Cutting Speed. At the same cross section of turnings and the same material being cut the endurance of the breakdown tests depends largely upon the cutting speed. The influence of the latter is a very remarkable one. At an increase of the cutting speed for 2 to 3 meters, the endurance decreases to half the amount under the same conditions. Worthy of observation is the sudden drop of the speed-endurance curve for a test time of 20 minutes. With the cutting speed increased, the endurance decreases quickly, while very long cutting periods are obtained when the cutting speed decreases. The time of cutting at the breakdown test shall also amount to about 20 minutes. Breakdown tests with cutting times of a few minutes or even a few seconds are unreliable.

Influence of the Tensile Strength of the Steel, Being Cut. The cutting time decreases very much with increasing tensile strength; besides the latter, other physical properties also play an important part, e. g. the elongation, the reduction of area, the yield point, the microstructure, the ability of cold hardening and last but not least, the purity of the steel.

On austenitic manganese steel, containing 12 per cent manganese, it is seen that the tensile strength alone is no criterion of the machinability. Of great influence is the microstructure of the steel being cut; hard carbides accelerate the destruction of the cutting edge.

Test results are to be judged with greatest caution as it is very difficult to have all conditions influencing the cutting time under control.

The author has shown to what a high degree the results of the breakdown test are influenced by the heat treatment, the cutting speed and the properties of the steel being cut and the difficulties, offering opposition to the attempt to require that high speed steels have precise numerical values. The difficulties lying in the fluctuation of the heat treatment could even be surmounted by testing a series of cutters, but it is impossible to guarantee the uniformity of the material being cut. The unknown properties of a new material, influencing the result of the cutting test, are taken into consideration in that manner, so that there is made in the first place a cutting test with a normal cutter of known quality. In judging the results of tests of new steels, the results obtained with the normal cutter, are taken as basis. Only in this way is it pos-

sible to determine the ability of high speed steels and to overcome the difficulties offering opposition to their exact estimation.

The destruction of the cutting edge is caused by two conditions: the mechanical wear and tear and the destruction of the martensite hardness. It should be known what portion falls to each of these components and in what manner these portions vary in different materials and in the different modes of machining. Then we would be better able to judge high speed steel.

Abstracted by Dr. Hans Pollack, Germany.

DETERMINING THE WEIGHT OF ALLOY ADDITIONS. By R. S. Kerns. In *Forging-Stamping-Heat Treating*, November, 1926, page 425.

The writer has prepared a chart whereby it is possible to tell the required weight of ferro-alloy, to be added to any weight of charge. The author explains the chart and sets forth the method of calculating the alloy conditions above 1.00 per cent. This is done by various formulae.

INFLUENCE OF THE SHAPE OF CEMENTITE ON THE HARDENING OF STEEL. By A. Pomp and R. Wijkander. Transactions of the Kaiser-Wilhelm-Institute für Eisenforschung, Düsseldorf. Vol, 8, Supply 2.

The shape of cementite in the "as-received" state is of great importance on the result of the hardening process, especially if articles produced in large numbers, such as pins, razor blades, pens, steel balls, etc., are to be hardened, or if continuous hardening procedures are employed, e. g. at the hardening of steel wire or band steel.

To investigate the influence of the shape of the cementite (laminated pearlite or spheroidized cementite) on the hardening of steel, the authors made calculations upon the size of the surface of the cementite. In agreement with Belaiew they supposed all cementite-lamellas in laminated pearlite to be of the same thickness and as circular disks; they further supposed that all the cementite-globules possess the same size.

If a lamella of the diameter D and the thickness h is divided into m balls of the diameter d and if the sum of the surfaces of all the balls is equivalent to the surface of the lamella, then is the number of the balls:

$$m = \frac{1}{18k^2} + \frac{1}{3k} + \frac{4k}{9} + \frac{2}{3}$$

wherein

$$k = \frac{h}{D}$$

The curve in the figure comprehends the values from m and k, coordinated to each other for which the surface of the lamella is equal to the sum of the surfaces of the balls formed from it. Below the curve the lamella has a greater surface and above of it a smaller one than the sum of the balls. The question whether the laminated or the spheroidized cementite possesses the greater or smaller surface in a steel of a certain percentage of carbon may not be answered without any more ado.

To clear up this question the authors developed the following formulas:

$$\text{The ratio } \alpha = \frac{\text{sum of the surfaces of the lamellas}}{\text{sum of the surfaces of the globules}} = \frac{0.046}{h}\sqrt{\frac{v}{n_k}}$$

wherein h, v and n_k signify:

h....the thickness of the lamellas,

v....the portion of the volume consisting of cementite (in per cent of the total volume) in a steel with C per cent carbon,

n_k....the number of the cementite globules existing on the unit of the surface of slide.

If the thickness of the lamellas or the number of the globules on a certain surface of slide is known, it is possible with the aid of that equation to determine whether the laminated or the spheroidized form of the cementite possesses the greater surface at equal portions of cementite.

To compare two samples of the same steel, containing both spheroidized cementite but of different size, with each other and amounts the number of the cementite globules on the unit of the surface n_{k1} and n_{k2}, so is the ratio of the two surfaces α_k:

$$\alpha_k = \frac{\sqrt{n_{k1}}}{\sqrt{n_{k2}}}$$

Comparing two samples containing laminated cementite of different thickness with each other and is the thickness of the lamellas h_1, respectively h_2, so is the ratio of the surfaces:

$$\alpha_1 = \frac{h_2}{h_1}$$

To verify these calculations the authors made hardening tests with a steel of 0.86 per cent carbon, showing the following structures that were obtained by different heat treating procedures:

(a) fine lamellas,
(b) coarser lamellas,
(c) coarsest lamellas,
(d) fine grains,
(e) coarser grains,
(f) coarsest grains,
(g) sorbite.

The tests were carried out with test pieces of 16 x 8 x 3 millimeters, which were heated in a salt-bath to 780 degrees Cent. (1436 degrees Fahr.) for 1; 1, 25; 1, 50; 1, 75; 2; 2, 25; 2, 50; 3 and 4 minutes and quenched in ice water.

The results of the Brinell hardness tests are shown in Fig. 2. The dissolution of the cementite takes place in the following sequence: sorbite, fine lamellas, fine globules, coarser lamellas, coarser globules, coarsest globules and coarsest lamellas and not according to the size of the calculated surfaces of the cementite as it may be seen in Table I.

The reason that the speed of dissolution of the cementite, measured by the hardness numbers of the test-pieces after quenching, does not depend solely from the calculated cementite surfaces lies in the different manner of dissolution of the respectively laminated spheroidized cementite. Regarding

TABLE I.

sample	structure	thickness of the lamellas resp. diameter of the globules in mm	calculated surface of cementite mm²/mm³	sequence of the dissolution resulting from the hardening tests.
g	sorbite	very small	very great	1
a	fine lamellas	0.000075 (appraised)	3440	2
b	coarser lamellas	0.00010 (appraised)	2580	4
c	coarsest lamellas	0.00015	1720	7
d	fine grains	0.00061	1270	3
e	coarser grains	0.00094	830	5
f	coarsest grains	0.00129	600	6

the dissolution of the cementite with increasing duration of heating in the microscope, it may be seen that the procedure in samples containing laminated pearlite is entirely different from that in those containing globules of cementite. The dissolution of the spheroidized cementite takes place in such a manner

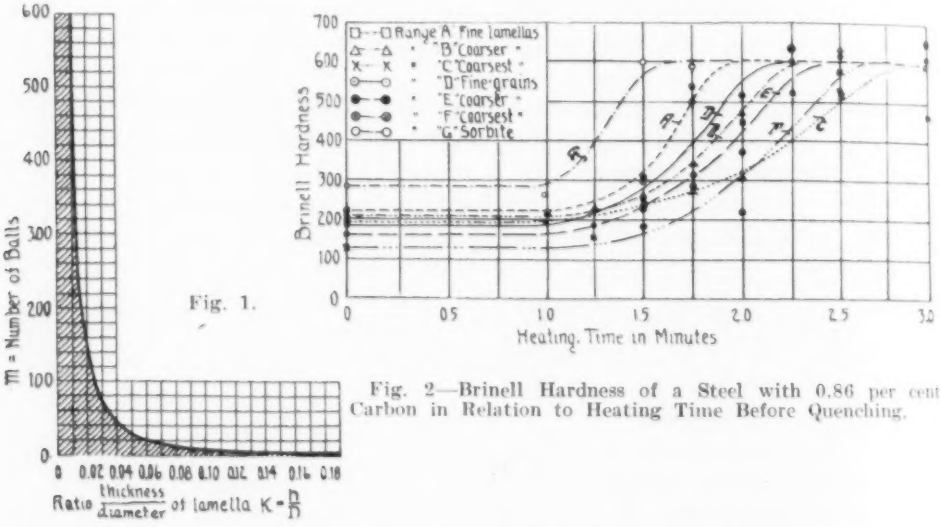


Fig. 1.

Fig. 2—Brinell Hardness of a Steel with 0.86 per cent Carbon in Relation to Heating Time Before Quenching.

that the globules of cementite are dissolved in the surrounding ferrite; after quenching the structure around the cementite globules consists of hardenite resp. troostite. In opposition to this procedure, the dissolution of the laminated cementite proceeds from the boundaries of the pearlite grains and advances from there into the interior of the grains until the dissolution has finished. The structure of such a steel consists after quenching of hardenite and pearlite. The different mechanism of the dissolution is the reason for the phenomenon, that laminated cementite takes up more heating time to be dissolved than it may be expected from the size of its surface.

As the samples of the range a correspond to an ordinary normal annealed steel and those of the range e to a generally used steel with cementite globules,

it may be concluded that the normal annealed eutectic steel may be hardened more easily than the same steel in the soft annealed state.

Besides, the form of the cementite plays an important part, i. e., the thickness of the lamellas and the diameter of the globules. The diameter and the number of the cementite globules in the samples d, e and f after the authors' calculation may be seen in the following table:

range	diameter of the cementite-gobules in 1	number cubic-millimeter.
d	0,00061 mm	1,065,000,000
e	0,00094 mm	300,000,000
f	0,00129 mm	113,000,000

These investigations evidently prove that at the same chemical composition and the same hardening procedure, the same mechanical properties are obtained only if the objects, to be hardened, possess all the same formation of structure.

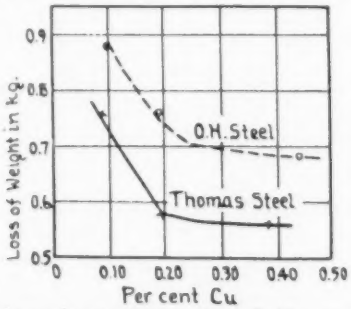
Abstracted by Dr. Hans Pollack, Germany.

THE RESISTANCE OF COPPER-CONTAINING THOMAS AND OPEN HEARTH STEELS AGAINST CORROSION. By Dr.-Ing. K. Daeves, Düsseldorf. *Stahl und Eisen*, May 6, 1926, pages 609-611.

The author describes briefly the corrosion tests, carried out by the A. S. T. M. on wrought iron and steel, containing a small percentage of copper and without copper, the copper bearing metals proving to have a considerable superiority over the plain metals against the attack of the atmosphere.

The results of similar tests, accomplished in Germany, were interpreted by O. Bauer in such a manner that an amount of copper was selected which showed the most advantageous effect, where an intensive action of sulphurous acid or carbonic acid is encountered.

To clear up this contradiction the author examined the results with the aid of the research of great figures. He obtained a curve showing the same



effect of the copper as Americans have found it; an amount of 0.25 per cent copper is particularly efficacious. It may be further seen that Thomas steel surpasses the open-hearth steel in corrosion-resistance and that the percentage of copper in Thomas steel is more effective than in open-hearth steel.

The results obtained by corrosion tests in the earth are not as clear as those in the atmosphere, but the superiority of Thomas steel and the influence of copper may also be seen in that case.

Abstracted by Dr. Hans Pollack, Germany.

HEAT BALANCE OF A HIGH PRODUCTIVE ELECTRIC MELTING FURNACE, TYPE HEROULT-LINDENBERG. By Dr.-Ing. Leif Lyche, Remscheid, and Dr.-Ing. H. Neuhaus, Solingen. *Transactions* of the Steel-Work-Committee of the Verein deutscher Eisenhüteenleute.

This report deals with the working results and the heat-balance of a 6-ton Heroult furnace of the Glockenstahlwerke, A.-G. vorn. Richard Lindenberg, Remscheid-Hasten, fitted out with a 2000KVA-transformer.

Formerly the furnace was fitted out with a transformer of 1175KVA and it has been rebuilt to a high productive furnace for economy's sake on time and on electric current in the melting period. In the melting period 173 volts and in the refining period 100 volts were used.

A comparison of the working results, during 10 months, of the furnace with the 2000 KVA-transformer with those of the same furnace fitted out with the formerly used 1175 KVA-transformer, rebuilt on 173 volts melting voltage, shows the reduction of the melting period to nearly half time with an economy in the consumption of current during the melting-down from 60 to 90KW/h per ton of the charge.

The consumption of electrodes increases. On the other hand the consumption of electrodes decreases from 15 to 13.5 kg per ton of the charge, when the melting down voltage of the 1175KVA-transformer is increased on 173 volts at constant effect.

The authors give a heat balance of the rebuilt furnace with the 2000KVA-transformer; the measurements were carried out on a heat of a carbon tool steel of the following chemical composition: carbon 1.03 per cent, manganese 0.32 per cent, silicon 0.39 per cent, phosphorus 0.026 per cent, sulphur 0.006 per cent and chromium 0.05 per cent.

The total thermal efficiency amounted 45.7 per cent, resp. 50.1 per cent; the thermal efficiency of the melting period was 68.2 resp. 70.0 per cent.

Abstracted by Dr. Hans Pollack, Germany.

METALLURGY OF THE CONVERTING PROCESSES. By Rutger von Seth, Assist. Kgl. Techn. Hochschule, Stockholm. *Zeitschrift des Vereines deutcher Ingenieure*, July 17, 1926, pages 973-979.

The purpose of this investigation is the study of the progress of heats by taking samples of metal, slag and gases during the blowing and the making up of complete material and heat balances.

The sampling of the metal and slag baths may only be carried out after tipping the converter; thereby the close mixture of metal and slag is abolished, the duration of melting is prolonged and the heat losses increase. The difficulties of the slag sampling during the Thomas process are mentioned. The temperature measurements of the gases is attended with great difficulties; the author obtained satisfactory results with the aid of a platinum, platinum-rhodium thermocouple.

Measurements of temperature were carried out with the Holbourn-Kurlbaum-pyrometer and because the temperature corrections, taking into consideration the not-black radiation, are still very imperfect. Comparing measurements were made with a platinum, platinum-rhodium thermocouple on pig iron. Measuring the temperatures of Bessemer pig iron both pyrometers

agreed well with each other within the ordinary limits of error; on basic pig iron the optical pyrometer indicated the temperature on an average 45 degrees Cent. (81 degrees Fahr.) to low. The Bessemer steel was tapped with the slag into the ladle; therefore it was not possible to aim at a pure metallic surface. The temperature reading was about 1500 degrees Cent. (2732 degrees Fahr.) for a steel of 0.70-1.00 per cent carbon. Tapping a Thomas heat the slag is first kept back and there are no difficulties to aim at pure metal and slag surfaces; the temperature of metal and slag was determined with 1650 degrees Cent. (3002 degrees Fahr.). The temperature of Bessemer pig iron and steel was not corrected, that of the basic pig iron was improved by 40 to 50 degrees Cent. (72 to 90 degrees Fahr.) and the temperatures of Thomas steel and slag were corrected according to a correction table given in *Stahl und Eisen* 1919, page 99; (emission capacity 0.40-0.65).

Further the author describes the sampling of gases and its difficulties.

The author investigated the Bessemer process in two Swedish steel works and the Thomas process in a Swedish and in a German plant.

The progress of the examined heats, the material balance of a Thomas heat and heat balances are shown by numerous diagrams and tables.

Abstracted by Dr. Hans Pollack, Germany.

MEASURES OF THE TRANSFORMERS FOR ELECTRIC ARC STEEL-FURNACES. By Dr.-Ing. F. Sommer, Duesseldorf-Oberkassel. *Transactions* of the Steel-Work-Committee of the Verein deutscher Eisenhüttenleute.

This paper deals with the influence of the transformer-measures on the melting effect and the consumption of energy of electric melting furnaces and purposes to give the possibility to lay down the most suitable transformer effect by calculation for any case.

For the measure of a transformer the energy consumption of the furnace during the melting period is decisive; this may be divided into two parts:

(1.) The consumption of energy being necessary for the transformation of the solid metallic charge into the liquid state (useful effect).

(2.) The amount of energy being necessary for the covering of the furnace losses during the melting period (lost effect).

These values were determined in the following manner: On a great number of heats the total energy-consumption, necessary for the liquefaction of the charge was measured. From this amount the useful effect, ascertained by calculation, was subtracted. The remainder, divided by the melting time is the effect used for the making good of the total losses of the furnace plant during the melting time.

With the aid of these values it is possible to calculate the nominal effect of the transformer after the following formula:

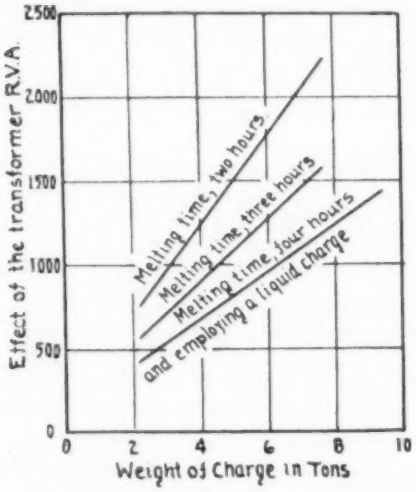
$$N = \frac{\frac{L \cdot G}{T} + S}{\cos \Phi}$$

N.....KVA, nominal effect of the transformer,

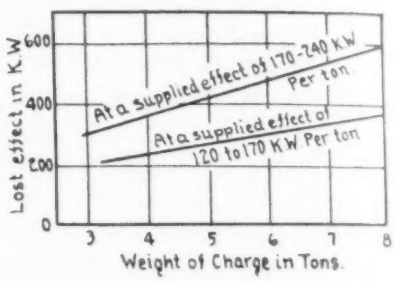
L.....KWh, theoretical consumption of energy for the liquefaction of 1 ton solid charge.

G.....tons, weight of the charge,
T.....hours, requested melting time,
S.....KW, effect required for making good the losses of the furnace plant during the melting time,
cos Φ.....factor of the electric effect of the furnace plant.

From the measured values of the consumption of electric energy for the melting down of 1 ton and the time required by it, the author develops the following diagram of the loss effects and shows how the required transformer



Effect of the Transformer at Different Melting Time and at Different Weight of the Charge.



Loss Effects of Electric Arc Furnaces Referred to Melting Time in Relation to Furnace Capacity and Heating Intensity.

effect may be calculated for furnaces of different size and of different melting effect; further the author gives a diagram from which the required transformer effect may be gathered. *Abstracted by Dr. Hans Pollack, Germany.*

DISCUSSION—CYANIDE BRITTLENESS

(*Continued from Page 964*)

accomplish this is to quench in water. We make this steel as hard as glass, if possible, and still have some ductility. But on some classes of product we are oil quenching after washing the cyanide from the parts, then reheating and oil quenching. This keeps our oil clean.

V. E. HILLMAN: That introduces an extra operation which would not be of interest to the production man, would it?

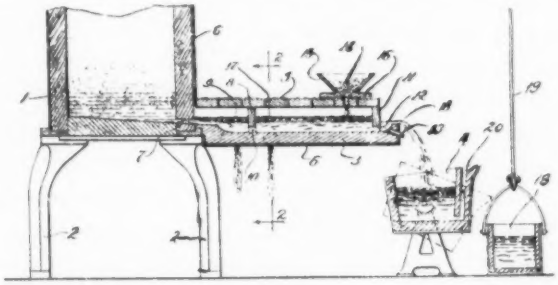
C. A. LAMPARD: I know, but if you have to meet these conditions this seems the only way out.

Reviews of Recent Patents

By
NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City
Member of A. S. S. T.

1,590,730, Method of Desulphurizing Iron, George S. Evans, of Oak Park, Illinois, Assignor, by Mesne Assignments, to The Mathieson Alkali Works of New York, N. Y., a Corporation of Virginia.

This patent describes a method of desulphurizing iron as it flows from the cupola without interrupting the routine foundry practice. The patent states that by the use of this method scrap or pig iron, containing a higher percentage of sulphur, may be safely remelted in the cupola and the sulphur content reduced to within the desired limits. The method comprises adding fused soda ash (sodium carbonate) to the stream of iron flowing from the cupola by means of an auxiliary mixing trough 3. This trough is provided with a skim gate 10 adjacent the cupola and a second skim gate 12 ad-

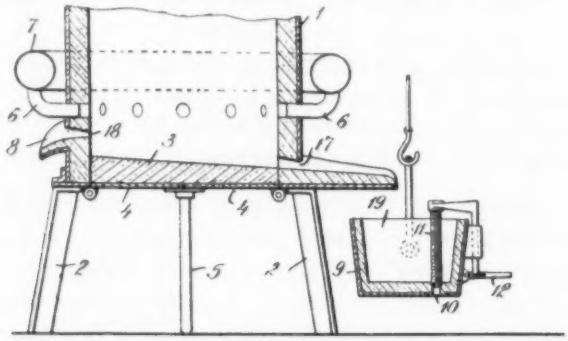


jacent the outlet of the mixing trough 3. A slag aperture 9 permits the slag trapped by the skim gate 10 to pass out of the mixing trough and an additional slag trough 17 permits the slag, resulting from the soda ash reaction, to flow from the mixing trough. The fused soda ash is introduced into the iron as it flows through the mixing trough by means of a hopper 15, located adjacent the outer end of the mixing trough. In this way the iron coming through the skim gate 10 comes in contact with a soda ash slag of low concentration and as it flows toward the end of the trough 3, the concentration of the soda ash is increased until the iron is subjected to the full strength of the soda ash adjacent the discharge point, where the sulphur content may be reduced to the desired limit. The operation of the process is continuous and does not interfere with the ordinary foundry practice. A mixing ladle 4 is illustrated as receiving the purified iron from the trough 3 and the pouring ladle is indicated at 18.

1,590,739, Purification of Iron, George S. Evans, of Oak Park, Illinois, Assigner to the Mathieson Alkali Works, of New York, N. Y. a corporation of Virginia.

This patent describes a similar process to the one above in which a mixing ladle 21 receives the iron from the cupola and in which the ladle is

of a sufficiently large capacity to maintain a relatively large pool of molten iron. In this pool, an alkaline refining slag is maintained which reduces



the suphur content of the iron. The fresh alkaline refining material, such as fused soda ash, is added to the mixing ladle as needed.

1,590,731, Refining of Iron, George Septimus Evans, of Oak Park, Illinois.

This patent describes a method of refining iron in the cupola, particularly to reduce the sulphur content thereof and therefore permit the use of coke or iron containing high percentages of sulphur by charging the cupola with bricks of fused soda ash, in addition to the normal cupola charge. These bricks are charged at the same time the lime stone is added and the charge is proportioned to secure the desired purification of iron.

1,601,541, Manufacture of Chromium Alloy Steel, Byramji D. Saklatwalla, of Grafton, Pennsylvania.

This patent describes the method of manufacturing high chromium steel having a low carbon content direct from chromium ore. The method is particularly intended for use with an open-hearth or electric furnace, and comprises forming a molten bath of steel having a metal layer containing carbon as the major reducing agent and a slag layer in which the chrome ore is incorporated, and maintaining the bath in the molten condition to cause a reaction between the carbon in the metal layer and the chrome ore in the slag layer to thereby directly reduce the chromium in the steel. The carbon content is predetermined by the chromium desired in the final steel.

1,601,787, Steel Alloy, Joseph W. Weitzenkorn, of Pittsburgh, Pennsylvania, Assignor to Molybdenum Corporation of America, of Pittsburgh, Pennsylvania, a Corporation of Delaware.

This patent describes a manganese steel alloy having the characteristics of both iron and steel in that it is hard and wear-resisting, tough, strong and dense. The alloy comprises 0.85 to 2.50 per cent carbon, 1.15 to 3.00 per cent manganese and from a fraction of one per cent to 1.25 per cent molybdenum, the remainder iron, except for the usual impurities. The increase in carbon content over that of the ordinary manganese steel appears to give the new results described.

1,602,274, Process for Detempering Steel, Evan James Lewis, of Canonsburg, Pennsylvania.

This patent describes the process of quickly detempering ordinary carbon or high speed steels so as to permit sharpening of the same or the like. The process comprises heating the tool in a suitable furnace or in a blacksmith's forge to a temperature of about 975 degrees Fahr., then permitting to cool to a dark red glow and quenching in a special liquid, which is prepared by dissolving 3 pounds of soda ash, and ¼ pound of soap in 5 gallons of hot water. The quenching liquid should be maintained at about 150 degrees Fahr. According to the inventor, the entire detempering process can be carried out within ½ hour.

1,602,995, **Nonferrous Alloy, William A. Wissler, of Elmhurst, New York, Assignor to Haynes Stellite Company, a Corporation of Indiana.**

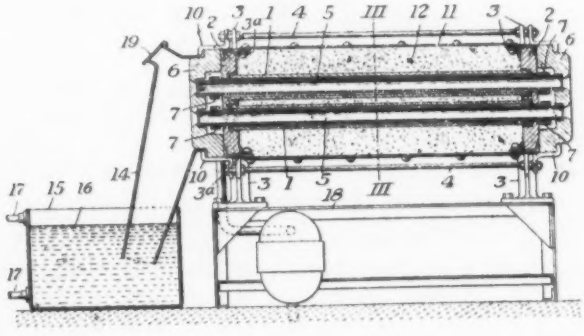
In this patent the inventor states that alloys of the type comprising cobalt and metals of the chromium group, which are especially adapted for use as cutting tools, may be substantially improved by the introduction of larger percentages of boron than have been heretofore used. The range of composition is indicated as follows:

	Per cent
Tungsten	20 to 30
Chromium	20 to 30
Carbon	0.75 to 2.40
Boron	0.40 to 2.00
Iron	0.0 to 5.00
Silicon	0.0 to 1.00
Cobalt	Balance.

For best results, the carbon content should be not more than 0.50 per cent above the boron content.

1,603,165, **Heat Treating Furnace, Hans O. Swoboda, of Edgewood, and Earl M. Richards, of Pittsburgh, Pennsylvania, Assignors to H. O. Swoboda, Inc., of Pittsburgh, Pennsylvania, a Corporation of Pennsylvania.**

This patent describes a heat treating furnace comprising suitable frame members 3, and a series of spaced refractory tubes 1, in insulating blocks 2. The tubes 1 are packed in suitable powdered insulating material

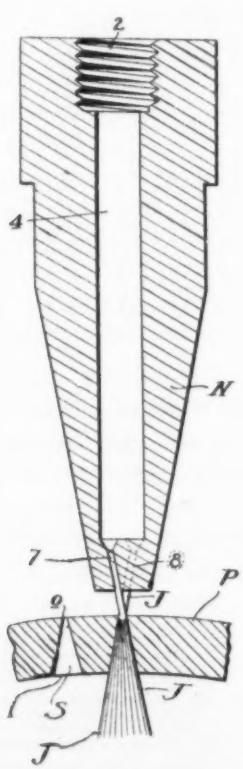


12 and all parts of the furnace are mounted so as to permit expansion and contraction thereof under heat. Inside each tube 1 a metal tube 5 is

positioned. The tubes 5 are electrically connected at the ends thereof by suitable straps 7. The tubes 5 are heated by the passage of electric current there through and the articles undergoing heat treatment are passed through the tubes 5 by insertion at the right and pushing through in a continuous procession either by hand or by some suitable pushing and feeding machine. At the opposite ends of the tube 5 a chute 14 conducts the heated articles into a quenching bath 16.

1,604,890, Acetylene Torch Nozzle, John B. Eastman and John G. Sniffin, of Los Angeles, California, Assignors, by Mesne Assignments, of One-Half to **Kobe, Inc., of Los Angeles, California, a Corporation of California; One-Fourth to Pacific Oil Tool Company of Los Angeles, California,** a **Corporation of California; and One-Fourth to Gilbert S. Beesmeyer,** of Los **Angeles, California.**

This patent describes an acetylene torch nozzle N provided with the usual central aperture 4 and having outlet nozzles 7 and 8 extending at an



angle to the end of the nozzle N and converging so as to concentrate the jets thereof at approximately the point of impingement of the jets upon the metal to be cut and thereafter to spread the flame, as at J, so as to cut with one operation, a kerf or slot at the inclined walls, as indicated at S.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested To Refer to Serial Numbers of Questions

QUESTION NO. 193. *Is S. A. E. steel 1120 or S. A. E 1112 screw stock which is rather high in phosphorus and sulphur any more liable to rust than ordinary cold-rolled shafting?*

ANSWER. It is understood that this question has been asked in relation to the use of screw stock for the manufacture of valve stems. Through the aid of one of our members who is intimately familiar with the manufacture of valves and valve parts, we are advised that the use of screw stock for valve stems should by all means be discouraged.

The American Engineering Standards Committees cooperating with the American Society of Mechanical Engineers and American Society for Testing Materials have adopted a standard for valves in which the sulphur content in no part of the valve should exceed 0.05 per cent. So far as is known no concern manufacturing valves uses cold-rolled steel spindles or screw stock for steam power plant or oil refining work regardless of the pressure, as it has become standard practice to use nickel-copper alloys, stainless iron or stainless steel. Screw stock and cold-rolled stock when subjected to steam will show quite an appreciable amount of corrosion. Furthermore high phosphorus steel is likely to produce shock brittleness.

QUESTION NO. 192. *What is the recommended practice for annealing 4 per cent silicon steel?*

QUESTION NO. 191. *Is there any available data on the temperature curve for breaking up the double carbides in an electric furnace steel having an approximate chemical analysis of 0.40% carbon, 1.00% chromium, 2.50% nickel and 0.80% manganese?*

QUESTION NO. 190. *What is the most suitable thickness of a copper plate coating to prevent carburization in the box type method of carburizing?*

QUESTION NO. 189. *What is the McQuaid-Ehn test and what are its merits in selecting steel for carburizing?*

ANSWER. The McQuaid-Ehn test for the "normality" or "abnormality" of steels for carburizing purposes has been described in several publications[1] and for a thorough exposition of this work the reader is referred to them. At the annual meeting of the society held in Detroit in September, 1922, E. W. Ehn presented a paper entitled "Irregularities in Case Hardened Work Caused by Improperly Made Steel" in which he described the McQuaid-Ehn test. As a result of this investigation described by these men it is understood that the requirements of the test were inserted in certain steel specifications calling upon the steel maker to comply with the provisions of the test. Just how universal this requirement has been made we are unable to say at this time.

[1]H. W. McQuaid and E. W. Ehn, "Effect of Quality of Steel on Case Carburizing Results"—American Society of Mining and Metallurgical Engineers, February, 1922, and E. W. Ehn—"Influence of Dissolved Oxides on Carburizing and Hardening Qualities of Steel"—Iron and Steel Institute, May, 1922.

In the last named paper Mr. Ehn makes the following comments which summarize his paper to an extent:

"Failure in case-hardening, especially in reference to soft spots, is often due to improper steel. Variation of structure of a carburized piece gives a direct indication whether the steel is suitable for carburizing or not.

"Coarse-grained structure in case and core of carburized steel with large crystals of pearlite, and clean-cut cementite areas in the hyper-eutectoid zone, are signs of good or normal steel. Curly cementite, disintegration of pearlite in hyper-eutectoid zone, and fine-grain size with rounded pearlite areas in the gradation zone and core are signs of an abnormal steel. Abnormal steel has a tendency to give a thin case of high-carbon content and to form soft troostitic spots in hardening.

"The structure of normal and abnormal steel varies with the carburizing temperature and the rate of cooling. Carburizing tests on a laboratory scale can easily be made.

"The variation in carburizing properties is caused by oxides uniformly distributed in solid solution in the steel. The ultimate cause is improper deoxidation of the steel when made, and no later treatment can change these properties.

"The influence of the oxides in regard to grain size is theoretically explained by their influence on the solidification of the steel in the ingot and their later obstructing action against grain growth. Disintegration of the pearlite in the hyper-euctectoid zone is caused by the solution pressure from the oxides in solution in the ferrite.

"The formation of soft troostitic spots in hardening of abnormal steel is explained by the action of the oxide particles as starting points for the troostite formation. This explanation is founded on the investigations of Portevin and Garvin on hardening of carbon steels.

"The results obtained in heat treatment of all kinds of steels, notably high and medium carbon steel, is dependent on the presence of oxides in the steel, and many mysterious failures, especially in hardening, are likely to find their explanation by carburizing; and a microscopical examination of the structures obtained."

QUESTION NO. 188. *What causes the scaling on the inside of holes of piston pins when heated in a Hoskins electric pusher type furnace? Does the sulphur content of the steel have any marked effect?*

QUESTION NO. 186. *Why should marking dies be rubbed with emery cloth before using?*

QUESTION NO. 185. *What precaution should be observed in designing such a tool?*

QUESTION NO. 183. *What effect, if any, have the additions of alloys on the internal stress of tool steels?*

QUESTION NO. 180. *Explain the effect of decarburization in grinding.*

QUESTION NO. 179. *What is the difference between grinding cracks and grinding checks?*

QUESTION NO. 171. *What is the hardness of carbon steels at elevated temperatures such as 400 to 1000 degrees?*

QUESTION NO. 169. *What is the hardness of high speed steel at elevated temperatures such as 400 to 1000 degrees?*

QUESTION NO. 165. *What importance should be placed on the carbon content of high speed steel?*

THE ENGINEERING INDEX

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Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each month with a specially prepared section of The Engineering Index. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the copy prepared for the annual volume of the Index published by the A. S. M. E.

In the preparation of the Index by the staff of the A. S. M. E. some 1,200 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. will be supplied with a selective index to those articles which deal particularly with steel treating and related subjects.

Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders. A separate print is required for each page of the larger periodicals, but whenever possible two pages will be photographed together on the same print. When ordering prints, identify the article by quoting from the Index item: (1) Title of article; (2) name of periodical in which it appeared; (3) volume, number, and date of publication of periodical; and (4) page numbers.

AIRPLANES

METAL AIRPLANES. Recent Development in the Construction and Operation of All-Metal Airplanes, C. Dornier, Nat. Advisory Committee for Aeronautics—Tech. Memorandum, no. 378, Sept. 1926, 23 pp., 24 figs. Tendency to use steel wherever possible is more pronounced today than ever before; new possibilities have been opened up by rustproof steels recently put on market; results of systematic experiments with all new steels and light alloys; brief review of development of landing gears and airplanes produced by author's company during last few years. Translated from Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt, May 1926.

ALLOYS

TERNARY. Constitution of Ternary Systems (Zur Fortentwicklung der Konstitutionsforschungen bei ternären Systemen), W. Guertler. Zeit. für anorganische u. allgemeine Chemie, vol. 154, June 6, 1926, pp. 439-455, 10 figs. Detailed account of means of differentiation between most valuable metal combinations and those which are of little technical use; considers three points of views: molten mixture must be homogeneous completely miscible mass; mixture must have all technically important properties of metallic substances, there must be certain stability towards air and moisture.

ALUMINUM

CASTINGS. Aluminum Casting Output, Its Difficulties, R. Micks. Can. Foundryman, vol. 17, no. 9, Sept. 1926, pp. 32 and 37-39, 6 figs. Difficulties involved in production of aluminum castings, and improvement in practice; use of chloride of zinc; describes two types of machines.

CORROSION. Corrosion and Protection of Aluminum (Korrosion und Schutz des Aluminums), L. Jabłonski. Korrosion u. Metallschutz, vol. 2, no. 9, Sept. 1926, pp. 213-218. Discusses divergent views as to corrosion, and tests carried out to determine corrosive action of sulphuric acid, nitric acid, fatty acids, alkalies, methyl and ethyl alcohol, nitrates, sulphates, chlorides, phenols, etc.

CORROSION. Corrosion Tests on Aluminium and Aluminium Alloys. Metallurgist (Supp. to Engineer, vol. 142, no. 3694), Oct. 29, 1926, pp. 156-157, 1 fig. Refers to two articles in Zeit. für Metallkunde, one in May 1925 issue, by F. Mylius, and one by H. Biegler, in Sept., 1926, issue; Mylius' test consists in exposing samples of metal to oxidizing solution of sodium chloride containing 1 per cent of salt and 3 per cent hydrogen peroxide; it has been adopted in modified form by Zeppelin Construction Co. at Friedrichshafen, Germany; Biegler describes more recent application of method, more particularly to study of intercrystalline corrosion. See reference to article by Mylius in Eng. Index, 1925, p. 31.

CORROSION. Oxidic Sodium Chloride Test and Intercrystalline Corrosion of Aluminum and Its Alloys (Oxydische Kochsalzprobe und interkristalline Korrosion beim Aluminium und seinen Legierungen), H. Biegler. Zeit. für Metallkunde, vol. 18, no. 9, Sept. 1926, pp. 288-289, 2 figs. Author recommends modifications of test described by Mylius in same journal, May 1925, and applies them to study of intercrystalline corrosion.

CORROSION RESISTANCE. Influence of Thermal and Mechanical Treatment of Aluminum on Its Resistance to Corrosion (Ueber den Einfluss der thermischen und mechanischen Behandlung von Aluminium auf seine Korrosionsbeständigkeit), W. Wiederholt. Korrosion u. Metallschutz, vol. 2, no. 5, May, 1926, pp. 126-133, 11 figs. Velocity of dissolution of aluminum sheet in acid increases with rise of annealing temperature to maximum at 300 deg., at which temperature maximum separation of impurities from solid solution in aluminum occurs, with consequent formation of greatest number of local elements; rate of corrosion of metal annealed below 300 deg. is proportional to time of

annealing; resistance to corrosion is increased by annealing in nitrogen and to greater extent by annealing in oxygen; results of tests carried out at Reichsanstalt, Germany. See brief translated abstract in Chem. & Industry, vol. 45, no. 42, Oct. 15, 1926, p. 830.

HEAT TREATMENT. Influence of Heat Treatment of Aluminum on its Rate of Dissolution in Hydrochloric Acid (Ueber den Einfluss der thermischen Behandlung von Aluminium auf seine Auflösungsgeschwindigkeit in Salzsäure), W. Wiederholt. Zeit. für anorganische u. allgemeine Chemie, vol. 154, June 6, 1926, pp. 226-237, 7 figs. Rate of dissolution of aluminum in hydrochloric acid probably depends on ease with which local electrical cells can be formed, and thus on extent to which impurities, chiefly silicon, are separated from mass of metal; dissolution is most rapid when aluminum has been heated to 300 deg.: at this temperature equilibrium is attained, and maximum separation of silicon occurs. See brief translated abstract in Chem. & Industry, vol. 45, no. 38, Sept. 17, 1926, p. 750.

ALUMINUM ALLOYS

AGING. Significance of Silicon in the Aging of Aluminum Alloys Containing Lithium or Magnesium (Die Bedeuting des Siliziums für die Vergütbarkeit des Aluminiums durch Li oder Mg), P. Assmann. Zeit. für Metallkunde, vol. 18, no. 8, Aug., 1926, pp. 256-260, 3 figs. Maximum hardness of alloys of lithium or magnesium with commercial aluminum, after quenching from above 500 deg. cent. and aging at 18 deg., is obtained when silicon impurity of aluminum is just sufficient to form silicides Li_8Si or Mg_2Si; with more or less silicon than this, hardness of aged alloy decreases proportionately to excess or deficiency; with very pure aluminum neither lithium nor manesium produces aging phenomena. See brief translated abstract in Chem. & Industry, vol. 45, no. 42, Oct. 15, 1925, p. 831.

ALPAX. Some Mechanical Tests of Cast Bars of Alpax, H. J. Tapsell. Aeronautical Research Committee—Reports and Memoranda, no. 1011, Dec. 1925, 9 pp., 2 figs. Results obtained from tests to determine mechanical properties at air temperature and at elevated temperatures of cast silicon-aluminum bars; it is shown that this material is valuable casting alloy; ultimate tensile strength compares favorably with that of chill-cast Y alloy.

Special Alpax Metals (Les Alpax spéciaux), M. Petit. Revue de Métallurgie, vol. 23, nos. 7 and 8, July and Aug., 1926, pp. 418-431 and 465-484, 53 figs. Discusses research work to obtain an Alpax metal of 13 per cent Si content, of better mechanical and physical properties, by addition of one or several other metals; heat treatment of special Alpax metals; velocity of cooling, etc.; micrographic examination; inconclusive results.

ALUMINUM-SILICON. The Constitution and Structure of the Commercial Aluminum-Silicon Alloys, A. G. C. Gwyer. Inst. Metals —Advance Paper, no. 404, for mtg. Sept. 1-4, 1926, 43 pp., 54 figs. Constitution, structure and mechanical properties of modified aluminum-silicon alloys; theory based upon colloidal lines is put forward to explain nature of modified structures; application of this theory to other alloy systems; alloys possess good founding qualities; are appreciably lighter than pure aluminum, and in both chill- and sand-cast states possess high resistance to shock, excellent ductility, and high degree of incorrodibility; contains appendix on properties of modified aluminum-silicon alloys. See also abstract in Foundry Trade Jl., vol. 34, no. 526, Sept. 16, 1926, pp. 247-250, 4 figs. and Engineering, vol. 122, nos. 3169 and 3170, Oct. 8 and 15, 1926, pp. 458-460 and 492-494, 10 figs.

BORIN IN. Borin in Aluminium and Aluminium Alloys. Metallurgist (Supp. to Engineer, vol. 142, no. 3694), Oct. 29, 1926, pp. 157-159, 1 fig. Review of paper by P. Haenni, published in Revue de Metallurgie, June, 1926, giving account of research carried out by author; results of tensile and hardness tests on binary alloys of boron and aluminum; corrosion tests; it would appear that boron is not detrimental and may increase resistance of aluminum to nitric acid.

CASTINGS. Aluminum-Alloy Permanent-Mold Castings, R. J. Anderson. Am. Foundrymen's Assn. — Preprint no. 5, for mtg. Sept. 27-Oct. 1, 1926, 29 pp., 10 figs. Indicates directions which have been taken by more recent developments in aluminum-alloy permanent-mold casting; discusses properties, mode of manufacture and fields of application, and gives comparison with sand and die castings; it is shown that aluminum-alloy permanent-mold castings have greater soundness, finer grain size, greater strength and hardness, greater resistance to impact and alternating-fatigue stresses, and greater resistance to corrosion than sand castings.

Recent Development in the Production of Aluminum-Alloy Castings, R. J. Anderson. Am. Metal Market, vol. 33, no. 180, Sept. 18, 1926, pp. 9-10, and 13-14, 9 figs. Applications of aluminum-alloy castings; alloys for castings production; melting in foundry practice; heat treatment of castings; sand-castings and die-casting practice; permanent-mold casting.

CONSTITUTION. Constitution of Alloys of Aluminum, Zinc and Tin and Aluminum, Zinc and Cadmium, V. Jares. Am. Inst. Min. & Met. Engrs. — Trans., no. 1588-E, for mtg. Sept. 1926, 15 pp., 17 figs. Results of experiments on binary and ternary alloys.

BLAST FURNACES

GRANITE CITY, MO. Second Stack Begins Campaign, J. D. Knox. Iron Trade Rev. vol. 79, no. 20, Nov. 11, 1926, pp. 1240-1242, 3 figs. Blast is applied to new blast furnace in St. Louis district in less than year after excavation work started; surplus gas is used for generating power for public consumption; description of layout.

HOLLAND. Measuring Air Volume by Chemical Method in Dutch Blast-Furnace Operation (Over luchtvolume-metingen, o.a. met de chemische methode, bij het Nederlandsche hoogovenbedrijf), F. W. Van Berckel. Ingenieur, vol. 41, no. 26, June 26, 1926, pp. 525-534, 5 figs. Discusses methods for calculating quantity of air supply, gas produced and distributed to boilers and preheaters; indicators and distance control.

LINING. Laying of Blast Furnace Linings, W. A. Stuart. Iron Trade Rev., vol. 79, no. 16, Oct. 14, 1926, pp. 990-992, 3 figs. Breaking all joints of circular brickwork gives tightly bonded wall, increases

mechanical safety factor, prolongs life of refractories and decreases labor costs; description of recently devised method.

MYSTIC IRON WORKS, EVERETT, MASS. Make Coke Pig Iron in New England for the First Time, H. R. Simonds. Iron Trade Rev., vol. 79, no. 14, Sept. 30, 1926, pp. 839-841, 3 figs. Furnace which is rated at 450 tons per day, is 88 ft. high, with 17-ft. hearth and 20-ft. 6-in. bosh; it is supplied by three hot-blast stoves of Freyn design, equipped with Hagen type automatic combustion-controlled gas burners. See description in Iron Age, vol. 118, no 19, Nov. 4, 1926, pp. 1277-1278, 3 figs.

OXIDATION PHENOMENA. The Influence of Oxidation Phenomena on Blast-Furnace Process (Ueber den Einfluss von Oxydationsvorgängen auf den Hochofenprozess), F. Wüst. Stahl u. Eisen, vol. 46, no. 36, Sept. 9, 1926, pp. 1213-1221, 8 figs. Comparison between catalon hearth and low hearth; importance of gas phase in metallurgical processes; reoxidation of iron before the tuyeres and heat volume generated in connection therewith; comparison between blast capacity, production and coke consumption.

SCRAP IN BURDENS. Iron and Steel Scrap in Blast-Furnace Burdens, W. C. McKee. Min. & Met. vol. 7, no. 238, Oct. 1926, pp. 435-437. Melting scrap in blast furnace common practice; effect on fuel consumption and opinions as to detectable effects on product.

SPECIFIC EFFICIENCY. Specific Efficiency of the Blast Furnace, R. Franchot. Min. & Met., vol. 7, no. 237, Sept. 1926, pp. 368-372 and (discussion) 372-374, 1 fig. Furnace burden now limited to that which can absorb less than half energy input is claimed by author. In discussion, T. L. Joseph questions these conclusions.

DIRECT PRODUCTION FROM ORES. Direct Production of Brass from Mixed Ores (Ueber die direkte Erzeugung von Messing aus gemischten Erzen), W. M. Guertler. Metallu. Erz, vol. 23, no. 11 1st June issue, 1926, p. 325. By melting sulphide ores of lead and zinc with metallic copper in excess, copper matte and mixture of metallic lead, copper, and zinc are formed, which separate, in liquid state, into layer rich in lead with little zinc, and copper-zinc layer with little lead; last-named is melted with copper and yields serviceable brass.

DIRECT PRODUCTION FROM ORES. Direct Production of Brass from Mixed Ores (Zur Frage der direkten Erzeugung von Messing aus gemischten Erzen), W. M. Guertler. Metallu. Erz, vol. 23, no. 17, 1st Sept. issue, 1926, pp. 468-482, 10 figs. Method of producing brass direct from a lead-zinc-copper ore; by melting mixture of galena, zinc blend with copper, three separate liquids are obtained, namely, copper matte with small lead and zinc contents; a metallic melt with small lead and varying zinc content; and a metallic lead rich melt, which can be separated in usual way from copper and zinc, and sold as lead.

EXUDATIONS. Exudations on Brass and Bronze, W. B. Price and A. J. Phillips. Am. Inst. Min. & Met. Engrs.—Trans. no. 1568-E for mtg. Sept. 1926, 9 pp., 6 figs. Calls attention to phenomena which authors have encountered; protuberances on admiralty brass, bronze and on leaded brass; theory of inverse segregation.

HOT ROLLING. Working of Brass at High Temperatures (Untersuchungen ueber die Warmverarbeitbarkeit des Messings), K. Hanser. Zeit. für Metallkunde, vol. 18, no. 8, Aug. 1926, pp. 247-255, 13 figs. Presents diagrams showing equilibrium diagram of copper-zinc alloys containing more than 50 per cent copper showing lines of equal compressibility (under static and dynamic pressure), hardness, tensile strength, elongation, and reduction of area; reduction in height of B-brass under dynamic blow remains fairly constant up to 500 deg. then increases rapidly with rise of temperature, whereas with A-Brass, slow but steady increase takes place throughout temperature range; results show that reduction in area is best indication of most suitable temperature for working brass.

MUNTZ METAL. Standardization of Microscopic Examinations of Muntz Metal Alloys, R. S. Pratt. Min. & Met., vol. 7, no. 237, Sept. 1926, pp. 374-375, 5 figs. Presents sketches adopted in preference to photomicrographs in laboratory of Bridgeport Brass Co., where it was felt that they could be more conveniently made to present exact type of structure desired.

PRESSED BARS. Technological Behavior of Pressed Brass Bars (Das technologische Verhalten gepresster Messingstangen), W. Köster. Zeit. für anorganische u. allgemeine Chemie, vol. 154, June 6, 1926, pp. 197-208. Structure of pressed brass bar changes along its length; at beginning it is granular, at end, a section appears more uniform and consists of fine grains of A-and-B-mixed crystals; mechanical properties vary correspondingly; change in structure along bar depends on conditions governing cooling of press block and on copper content of brass. See brief translated abstract in Chem. & Industry, vol. 45, no. 38, Sept. 17, 1926 p. 750.

WORKING PROPERTIES. The Working Properties of Brasses. Brass World, vol. 22, no. 10, Oct. 1926, pp. 325-326, 1 fig. German metallurgists report on investigations with many types of brass; hot-rolling problem when impurities are present in appreciable quantities. Translated from Zeit für Metallkunde.

BRONZES

COMMONLY USED. Bronzes in Common Usage, E. G. Jarvis. Brass World, vol. 22, no. 9, Sept. 1926, pp. 285-287. Formulas for preparing some of popular mixtures; effects of silicon, manganese, nickel, and phosphorus.

HEAT TREATMENT. Heat Treatment Improves Bronzes, N. K. B. Patch. Iron Age, vol. 118, no. 13, Sept. 23, 1926, pp. 841-842, 2 figs. Modern methods for control of crystal structure in castings; effect on aluminum bronze.

CASE HARDENING

DISTORTION. Predicting the Distortion of Heat-Treated Case-Hardened Rings, P. J. Haler. Engineering, vol. 122, no. 3170, Oct. 15, 1926, pp. 470-471, 2 figs. Points out that one of the greatest drawbacks to extended use of case-hardened parts is distortion; presents charts showing maximum and

minimum allowance which is to be left in bore of mild-steel work that is to be case-hardened before grinding; local distortion may be caused by unequal heating in furnace or pieces of scale adhering to piece during quenching; various factors help to give rapid cooling, such as high temperature of quenching, etc.

CAST IRON

FLAKE GRAPHITE IN. Coarse-Flaked Graphite in Cast Iron (Garschaumgraphit im Gusseisen) B. Osann. Stahl u. Eisen, vol. 46, no. 39, Sept. 30, 1926, pp. 1320-1324. Formation of graphite flakes with different melting processes; occurrences in special experimental pig-iron charges; influence of temperature and time; prevention of flakes. See also Giesserei-Zeitung, vol. 22, no. 20, Oct. 15, 1926, pp 565-568.

GRAPHITE IN. The Comparison of the Size and Distribution of Graphite in Cast Iron. Foundry Trade Jl., vol. 34, no. 526, Sept. 16, 1926, p. 237. For general purposes most satisfactory method of comparing size and distribution of graphite in different specimens is use of comparative microstructures carefully prepared under comparative and standard conditions.

GROWTH. The Effects of Various Alloys on the Growth of Gray Iron Under Repeated Heatings, R. R. Kennedy and G. J. Oswald. Am. Foundrymen's Assn.—Advance Paper, no. 25, for mtg. Sept. 27 - Oct. 1, 1926, 11 pp., 5 figs. Work undertaken with idea of developing gray iron having slow rate of growth under repeated heatings above critical range, and which could be reproduced by addition of various alloys to gray iron in ladle.

HEAT AND SCALE RESISTANCE. Heat and Scale Resisting Cast Irons, O. Smalley. Am. Foundrymen's Assn. — Advance Paper, no. 12, for mtg. Sept. 27—Oct. 1, 1926, 33 pp., 15 figs. Deals with high-duty castings; chilling irons and scale-resisting castings; semi-steel and influences of graphitizers; annealing process for car wheels and reasons for certain wheels giving better test results than others; mechanism of breaking down of ordinary white iron under heat-oxidizing conditions. See also Foundry Trade Jl., vol. 34, nos. 529 and 531, Oct. 7 and 21, 1926, pp. 303-305 and 343-347, 14 figs.

HIGH-DUTY. Progress in the Production of High-Duty Cast Iron, E. Piwowarsky. Am. Foundrymen's Assn.—Advance Paper, no. 23, for mtg. Sept. 27 - Oct. 1, 1926, 68 pp., 29 figs. Reviews development of quality of gray cast iron in Germany; low melting temperatures vs. superheating; theories developed by science of crystallization; conclusions drawn from investigation of heated mold sections; relation between chemical composition and superheating and melting temperatures and contraction; theories based on formation of graphite above critical temperature; process for reducing high-grade cast iron; conclusions drawn from dilatometer and growth tests; relation of graphite size and growth; effect of heating in oil and cooling in liquid air; effect of superheated steam.

NICKEL. Characteristics of Nickel and Nickel-Chromium Cast Iron. Am. Mach. vol. 65, no. 20, Nov. 11, 1926, p. 799. Reference-book sheet.

CHROMIUM STEEL

PROPERTIES. Chromium Alloys in Chemical Plant Equipment, C. E. MacQuigg. Chem. & Met. Eng., vol. 33, no. 10, Oct. 1926, pp. 609-611, 1 fig. High tensile strength and resistance to oxidation at high temperatures, workability and relative cheapness are characteristic of chromium irons.

PROPERTIES. High-Chromium Irons and Steels for Severe Service, T. H. Nelson. Chem. & Met. Eng., vol. 33, no. 10, Oct. 1926, pp. 612-613, 2 figs. Stainless steels have extremely wide range of properties which make them adaptable to unusual problems in chemical and allied industries.

COPPER

CUPROUS OXIDE IN. Metallographic Observations on Cuprous Oxide in Copper (Einige metallographische Beobachtungen an Kupferoxydul im Kupfer). P. Siebe. Zeit. für anorganische u. allegemeine Chemie, vol. 154, June 6, 1926, pp. 126-129. In normal cast copper, cuprous oxide forms bands of eutectic surrounding grains of copper; beads of eutectic are larger the slower the cooling: when copper is rolled, beads of eutectic become oval and form lines in direction of rolling; when copper is heated at 1000 deg. beads of cuprous oxide increase in size; in air, oxygen is absorbed and eutectic is gradually formed throughout mass.

COPPER ALLOYS

COPPER - BERYLLIUM. The Copper-Beryllium Alloys, M. G. Corson. Brass World vol. 22, no. 10, Oct. 1926, pp. 314-320, 27 figs. Tests with rare metal show its possibilities as hardening agent for copper; in some proportions product is similar to gold in color; resists tarnishing.

COPPER-NICKEL RESISTENCE. Electrical Property of Copper-Nickel Resistance Alloys, S. Kimura and Z. Isawa. Electrotechnical Laboratory (Japan) — Researches, no. 171, May 1926, 10 pp. 8 figs. Determination of relation between electrical resistance and chemical composition copper-nickel alloys; resistance change with temperature is measured from minus 200 to plus 800 deg. cent. (In English).

CORROSION

METALS. Corrosion of Metals, Theory and Experiments (Die Korrosion der Metalle, Theorie und Versuche), Palmaer. Korrosion u. Metallschutz, vol. 2, nos. 1 and 3, Jan. and Mar. 1926, pp. 3-8 and 57-62, 15 figs. Discusses velocity of solution of metals in acids, water, etc.; experiments with zinc and aluminum; corrosion of iron; composition of rust; concludes that solution and corrosion at ordinary temperature must be explained on theory of local elements.

CUPOLAS

MELTING STEEL CHARGES. Melting Synthetic Iron in the Cupola, F. Hudson. Foundry, vol. 54, no. 21, Nov. 1, 1926, p. 857. Describes practice in melting metal produced from all-steel charge.

CYLINDERS

OXYGEN PURITY AND TEMPERATURES. Relative Effect of Oxygen Purity and Temperature in Metal Cutting, F. P.

Wilson, Jr. Gen. Elec. Rev., vol. 29, no. 10, Oct., 1926, pp. 722-727, 10 figs. Difference between cutting efficiency of 98.5 and 99.5 pure oxygen controversial; comparative tests show definite savings of much greater magnitude by preheating oxygen; maximum economy obtainable by using cheaper gas with preheat; preheat also facilitates quick starting, and eliminates moisture troubles and hardening face of cut.

PRODUCTION SAW. Racine "Shear-Cut" Production Saw. Am. Mach., vol. 65, no. 18, Oct. 28, 1926, p. 729, 3 figs. Machine for high-speed metal cutting being built by Racine Tool & Machine Co., Racine, Wis.

CYLINDERS

HOLLOW, COLD WORKING OF. The Strengthening of Hollow Cylinders by Cold-work. Metallurgist (Supp. to Engineer, vol. 142, no. 3694), Oct. 29, 1926, pp. 155-156. Refers to account of early development of process as applied to guns, especially of work by Jacob on process known as "autofrettage" or self-shrinkage; points out that magnitude of internal stresses calculated by Jacob is misleading; work of numerous investigators has shown that steel overstrained in tension (as are inside layers of cylinder) has elastic limit in compression diminished; refers to Langenberg's work on effect of cold working on strength of hollow cylinders (Am. Soc. Steel Treating—Trans., 1925, p. 447), emphasizing effect of low-temperature annealing of overstrained cylinder.

DIES

PRESS. Wear of Dies and the Steel Problem for Hot Pressing (Gesenkverschleis und Stahlfrage in der Warmpresserei), W. Spitzner. Maschinenbau, vol. 5, no. 19, Oct. 7, 1926, pp. 880-887, 18 figs. Discusses investigation to determine causes of wear in dies for hot pressing of screws; question of suitable steels for dies; for mass production chromium-nickel and chromium-tungsten steel are recommended.

PRESS. Increasing Life of Dies for Hot Pressing of Brass (Die Erhöhung der Lebensdauer von Gesenken für das Warmpressen von Messing), A. Aronheim. Maschinenbau, vol. 5, no. 19, Oct. 7, 1926, pp. 887-892. Discusses characteristics of fall hammer, hydraulic press, etc., and their effect on dies; choice of suitable steels for dies and their heat treatment; use of hardened nickel-chromium steels.

DURALUMIN

CORROSION. Duralumin and its Corrosion, W. Nelson. Aviation, vol. 16, no. 18, Nov. 1, 1926, pp. 738-741, 4 figs. Complicity of corrosion problem; factors governing corrosion; corroding mediums; effects of salt atmosphere and of fuel; contact and induced corrosion; corroding solutions.

ELECTRIC FURNACES

ANNEALING. Annealing Iron and Steel in the Electric Furnace. Nat. Elec. Light Assn.—Report, no. 256-281, Aug. 1926, 5 pp., 4 figs. Electric furnace gives uniform high quality of product, minimizes labor of attendance, reduces losses, gives greater productive capacity without increase of labor, saves cost of annealing boxes and energy for heating same, and contributes greatly to reduction and elimination of labor turnover.

ANNEALING ALUMINUM IN. Annealing Aluminum in the Electric Furnace. Nat. Elec. Light Assn.—Report, no. 256-283, Aug. 1926, 3 pp., 2 figs. Electric furnace produces heat-treating method in which heating may be constant, physical properties kept uniform and all blistering may be prevented; no combustion products are present and therefore no impurities are introduced into metal; installation data.

BRASS. Annealing Brass and Copper in the Electric Furnace. Nat. Elec. Light Assn.—Report, no. 256-291, Aug. 1926, 3 pp. 3 figs. Electric furnace for brass annealing has removed all chance because of automatic temperature control, not only of muffle temperature, but also of temperature of charge itself; results of installation in Connecticut have proved that electric brass annealing is more economical than annealing with wood fuel; results of electric-furnace installation at Rome, N. Y.

Melting Brass in the Electric Furnace. Nat. Elec. Light Assn.—Report no. 256-287, Aug. 1926, 6 pp. 3 figs. Summary of disadvantages of fuel-fired furnaces and advantages of electric furnaces; induction, direct-arc, indirect-arc, indirect-resistance, combinations of previous principles, and high-frequency furnaces.

HIGH-CURRENT 3-PHASE LOAD. Asymmetrical High-Current 3 Phase Load (Untersuchung unsymmetrischer Dreiphasen-Hochstromanlagen), R. Stein. Siemens-Zeit., vol. 6, no. 7, July 1926, pp. 317-330, 8 figs. Considerable difficulty due to unequal reactance in heavy copper lines is experienced in electrochemical plants where 3 phase arc or resistance furnaces receive their low-voltage and high-current supply from transformers near by; aside from unbalanced load, a wattless component occurs which demands at transformer higher voltage than furnace or mere line drop would need; these conditions were analyzed by author, and results of great many measurements are given in vectorial representation and in tables; for absolutely perfect balance between phases use of interconnected current tranformers, one in each phase, is recommended.

MELTING. Melting Steel and Gray Iron in the Electric Furnace. Nat. Elec. Light Assn.—Report, no. 256-284, Aug. 1926, 6 pp., 4 figs. Discusses advantage of electric furnaces for this purpose.

TEMPERING. Rotary Tempering Furnace for Gears. Iron Age, vol. 118, no. 15, Oct. 7, 1926, pp. 1001-1002, 2 figs. Continuous electric, rotary-type, oil-tempering furnace with automatic control installed in plant of Warner Gear Co., Muncie, Ind.; it is used for heat treating gears and is said to be first continuous oil-drawing furnace ever built; designed by Strong, Carlisle & Hammond Co., Cleveland.

THERMAL INSULATION. Thermal Insulation of Electric Furnaces, M. L. Hartmann and O. B. Westmont. Am. Electrochem. Soc.—Advance Paper, no. 12, for mtg. Oct. 7-9, 1926, pp. 155-176, 15 figs. Gives thermal conductivities of fused alumina, fused magnesia, fireclay and high-temperature insulating refractory; mean specific

heat curves for these refractories are also given; suggests possibilities of energy conservation in electric furnaces by properly designed composite walls.

ELECTRIC WELDING

BUTT. On Electric Butt Welding, T. Okamoto. Inst. Elec. Engrs. Japan— Jl., no. 457, Aug. 1926, pp. 885-898, 16 figs. Deals with butt welding of soft steel bars. (In Japanese, with brief English abstract).

GAS HOLDERS. Electric Welding Steel Gas Holders, G. T. Horton. Can. Engr. vol. 51, no. 10, Sept. 7, 1926, pp. 277-279, 3 figs. Tendency towards heavier and more economical construction; welding various parts of gas holders; advantages of spherical pressure containers for gas or oil. Paper presented at Can. Gas Assn.

HIGH-CHROMIUM ALLOYS. The Welding of High-Chromium Alloys Intended to Meet Extreme Conditions, S. M. Norwood. Am. Electrochem. Soc.—Advance Paper, no. 10, for mtg. Oct. 7-9, 1926, pp. 133-136. Author has overcome obstacles inherent in welding of alloys containing more than 10 per cent chromium by addition of 8 per cent nickel to high-chromium alloys; objection of diminished corrosion resistance to sulphur products, generally accompanying addition of nickel, has been removed by addition of 2 per cent silicon.

ELECTRIC WELDING ARC

HYDROGEN. Welding with the Atomic Hydrogen Flame, R. A. Weinman. Am. Welding Soc.—Jl., vol. 5, no. 10, Oct. 1926, pp. 69-76, 14 figs. Results attained in research laboratory of General Electric Co. with this process indicate quite clearly that welds can be made by it which cannot be made by any other known means; however apparatus is hardly out of laboratory stage, and requires further development to suit general commercial conditions.

PIPES. First All-Arc Welded Water Pipe Line, W. L. Warner. Am. Welding Soc.—Jl., vol. 5, no. 9. Sept. 1926, pp. 19-23, 5 figs. What is said to be first completely arc welded pipe line in United States and longest pipe line of its type, was recently completed for city of Vallejo, Cal.; it has a length of 22 miles, and is steel-plate construction, all seams being electric-arc welded.

STAINLESS STEEL. Arc Welding Stainless Steels, W. C. Johnson. Welding Engr., vol. 11, no. 10, Oct. 1926, pp. 35-38, 16 figs. Industrial Welded Products Co. has developed electric welding of chromium irons to high point of perfection, after long period of experimentation and research; it is now possible to make welds in high-chromium low-carbon plate having same chemical analysis as plate itself.

STEEL PIPE. Progress of Welded Pipe Lines for Oakland Water-Supply. Contractors' & Engrs'. Monthly, vol. 13, no. 3, Sept. 1926, pp. 71-72, 3 figs. Steel pipe fabricated by new process of arc welding used throughout.

STRUCTURAL STEEL. Arc Welds in Structural Steel, A. M. Candy and G. D. Fish. Welding Engr., vol. 11, no. 9, Sept. 1926, pp. 30-33, 7 figs. Tests show that ultimate strength of structural members can be obtained and special designs are needed.

STRUCTURAL STEEL. Electric Arc Welding in the Manufacture of Structural Steel, A. G. Bissell. Am. Welding Soc.—Jl., vol. 5, no. 9, Sept. 1926, pp. 24-34, 13 figs. Following points indicate stability of arc welded joints; deposited metal in arc welded joint develops average of 60,000 lb. per sq. in. tensile strength, and 50,550 lb. per sq. in. in shearing strength; such joints proved strong enough to remain intact while structural steel members were badly deformed under static load of 40 tons; when subjected to vibration of 1760 reversals per minute, arc welded joints surpassed standard riveted joints in permanence, and showed longer life than structural material joined by it; from results of tests, it is concluded that arc welded joints are capable of withstanding any stresses that structural members will withstand without deformation and will remain intact even after structural members are deformed or broken.

STRUCTURAL STEEL. Structural Steel Joints Fundamentally Designed for Arc Welded Connections, A. M. Candy. Am. Welding Soc.—Jl., vol. 5, no. 10, Oct. 1926, pp. 76-92, 12 figs. Describes design of test specimens, and design for welded steel building for Westinghouse Electric & Mfg. Co. at Sharon, Pa.; testing work was carried on at Carnegie Inst. of Technology.

ELECTRIC WELDING

SEAMS. Welding Tight Seams Quickly. Welding Engr., vol. 11, no. 10, Oct. 1926, pp. 55-56, 6 figs. Team work between resistance seam welder and spot welder speeds up production program of electric-dishwasher factory.

FERROALLOYS

ADDITIONS, DETERMINING WEIGHT OF. Determining the Weight of Alloy Additions, R. S. Kerns. Blast Furnace & Steel Plant, vol. 14, no. 10, Oct. 1926, pp. 439-441, 1 fig. Author has prepared series of curves which make it possible to quickly determine amount of ferroalloy to be added to any weight of charge.

FORGING

ELECTRICALLY DRIVEN PRESSES. A New Type of Electrically Driven Forging Presses (Eine neuartige elektrisch betriebene Schmiedepresse), A. Friederici. Zeit. des Vereines deutscher Ingenieure, vol. 70, no. 39, Sept. 25, 1926, pp. 1288-1290, 8 figs. Use of forging presses and hammers; economic and technical superiority of electrically driven forging presses over hammers and presses heretofore in use.

FURNACES. Economically Operated Forging Furnace, G. L. Davis. By Mech. Engr., vol. 100, no. 10, Oct. 1926, pp. 632-633, 1 fig. Oil-fired adaptation of older type of down draft, coal-burning forge.

PRESSES. The Largest Steam-Hydraulic Forging-Press, W. J. Priestley. Min. & Met. vol. 7, no. 238, Oct. 1926, pp. 426-429, 5 figs. Notable war-time achievement described for first time; press used for forging armor, as well as bending and rectifying it, and forging ingots for large caliber guns.

UPSET PROCESS. Forging by the Upset Process, J. C. Kielman. Am. Soc. for

Steel Treating—Trans., vol. 10, no. 4, Oct. 1926, pp. 599-614, 11 figs. Deals with forgings used in manufacture of ball bearings; discusses steel and its peculiarities, and method of forging it; explanation of upsetting process and advantages of method compared with other methods; problems of forging dies and steels used in making them, and importance of heat treatment of tools; furnaces used for upset forging.

FOUNDRIES

PROGRESS. Fifty Years of Foundry Progress, S. G. Smith. Foundry Trade Jl., vol. 34, no. 531, Oct. 21, 1926, pp. 349-352. Survey of author's experience touching upon phases of work that have made some advancement in recent years; status of foundryman; methods of molding and modern appliances; drying and baking stoves; melting; progress in use of metals; pouring temperatures, heat treatment and alloying; research work.

FURNACES, GAS

RADIANT - HEAT. A Radiant-Heat Furnace. Gas Jl., vol. 175, no. 3302, Sept. 1, 1926, p. 474, 2 figs. Patented design was invented and applied by Wollers of Krupp Laboratories; its chief characteristics are (1) heating is entirely by radiation without flame formation, and consequently without disadvantages of flame contact with contents; (2) intimate admixture of gas and air (latter heated in recuperator) is effected in early stages.

FURNACES, HEAT TREATING

GAS - FIRED. Gas in an Automobile Plant, C. H. Lekberg. Am. Gas Jl., vol. 125, no. 22, Oct. 30, 1926, pp. 539-544. Describes continuous heat-treatment furnaces in Studebaker plant, South Bend, Ind.; carbonizing furnaces; hardening furnaces; burners.

FURNACES, INDUSTRIAL

DEVELOPMENTS. Industrial Furnaces (Industrieöfen), L. Weiss. Zeit. des Vereines deutscher Ingenieure, vol. 70, nos. 39 and 41, Sept. 25 and Oct. 9, 1926, pp. 1281-1287 and 1359-1361, 33 figs. Historical development of reverberatory-furnace design in relation to metallurgical industry; development of electric arc in connection with aluminum production; fuels employed and their calorific values; different types of melting and annealing furnaces of latest designs; calculation of their fuel consumption and efficiency.

HEAT INSULATION. Selection of Proper Furnace Insulation, M. H. Mawhinney. Forging — Stamping — Heat Treating, vol. 12, no. 9, Sept. 1926, pp. 328-333, 12 figs. Also Blast Furnace & Steel Plant, vol. 14, no. 10, Oct. 1926, pp. 426-431, 12 figs. Suggestions for selection of proper furnace insulation for various conditions which are commonly found in practice.

OIL BURNING. Piping Systems for Oil Burning Furnaces, C. C. Hermann. Machy. (N. Y.) vol. 33, no. 3, Nov. 1926, pp. 201-203, 4 figs. Analyzing average complaint of given industry using present-day oils, it is generally found that entire trouble is due to lack of recirculation of oil; shows how objectionable features of dead-end system have been eliminated by utilization of recirculation of oil.

FURNACES, METALLURGICAL

PULVERIZED - COAL - BURNING. Pulverised Fuel in Metallurgical Furnace Practice, L. P. Sidney. Metal Industry (Lond.) vol. 29, no. 10, Sept. 3, 1926, pp. 215-220, 5 figs. Account of Buell system and its applications; salient points in this system as applied to metallurgical furnaces are: air control is absolute; atomization of fuel, its intimate admixture with air, etc., enable complete combustion to take place within five or six feet of burner; flame is horizontal and velocity can be adjusted so that long travel is not required for complete combustion; temperature can be controlled with facility and is uniform throughout furnace; secondary air can be preheated; estimated saving of fuel is estimated as ranging from 20 to 50 per cent.

FURNACES, REVERBERATORY

RELINING. Relining Smelting Furnaces, V. Weinod. Metal Industry, vol. 29, no. 12, Sept. 17, 1926, pp. 273-274. Fettling; considerations as to roof; brickwork; structural aspects.

IRON

PASSIVITY. Passivity and Corrosion of Iron, L. McCulloch. Am. Electrochem. Soc. —Advance Paper, no. 15, for mtg. Oct. 7-9, 1926, pp. 197-205. Describes two new instances of passivity; progressive rusting of iron is ascribed to catalytic action of soluble iron salts, which are held upon iron surface by coating of rust.

STAINLESS. Stainless Iron has Unusual Merits, T. W. Downes. Iron Age, vol. 118, no. 19, Nov. 4, 1926, pp. 1265-1268, 3 figs. Results of tests of low-carbon, chromium-iron alloys at Naval Aircraft factory show ease of fabrication when annealed; stainless iron resists corrosion and its strength is increased by heat treatment.

IRON ALLOYS

ALLOTROPIC TRANSFORMATIONS. Allotropic Transformations in Iron-Silicon, Iron-Phosphorus and Iron-Manganese Alloys. Metallurgist (Supp. to Engineer, vol. 142, no. 3694), Oct. 29, 1926, p. 160. Review of work by Esser and Oberhoffer in Berichte der Fachausschüsse des Vereins deutscher Eisenhüttenleute, no. 69, Nov. 5, 1925; authors employed differential dilatometer to investigate effect of silicon, phosphorus and manganese on iron; shows that silicon and phosphorus are very similar in their effects in certain respects; effect of manganese is very different, and resembles more closely results obtained on addition of carbon or nickel to iron. See reference to original article in Eng. Index 1925, p. 416.

CEMENTATION. Cementation of Alloys of Iron and Copper by Tungsten, Molybdenum and Tantalum (Cementation des alliages ferreux et cuivreux par le tungstene, le molybdène et le tantale), J. Laissus. Académie des Sciences—Comptes Rendus, vol. 182, no. 19, May 10, 1926, pp. 1152-1154. Extent of cementation was determined by measuring depth of penetration seen in microsections; effect of temperature was investigated for 800, 900, 1000, 1100 and 1200 deg. Cent., and time of heating varied from 2½ to 10 hrs.

IRON - CARBON. Heat of Formation of Cementite as Electrolyzed from a Pure Iron

Carbon Alloy of Eutectoid Structure and Composition, G. H. Brodie, W. H. Jennings and A. Hayes. Am. Soc. for Steel Treating—Trans., vol 10, no. 4, Oct. 1926, pp. 615-629, 2 figs. Results of calorimetric determination of heat of formation of iron carbide; value of 13580 calories per gram molecule was obtained at 86 deg. Fahr.; work establishes fact that results of Campbell and that of Schenk are in error.

IRON - CHROMIUM - CARBON. The Ternary System Iron-Chromium-Carbon (Die heterogenen Gleichgewichte Liquidus-Solidus in dem Ternären System Eisen-Chrom-Kohlenstoff). A. von Vegesack. Zeit. für anorganische u. allgemeine Chemie, vol. 154, June 6, 1926, pp. 30-60, 7 figs. Iron and chromium form continuous series of mixed crystals; melting point is depressed when chromium is added to iron to minimum of 1490 deg. with 28 per cent of chromium, and then rises to that of chromium, which is above 1700 deg.; carbon content of alloys after fusion was always less than 0.1 per cent; microscopic structure of alloys containing less than 30 per cent of chromium depends on their heat treatment. Bibliography. See brief translated abstract in Brit. Chem. Abstracts, Aug. 1926, p. 799.

IRON - NICKEL. An Investigation of the Physical Properties of Some Nickel-Iron Alloys of the Invar Group, E. A. Blomqvist. Rensselaer Polytechnic Inst. — Eng. & Science Series, no. 13, June 3, 1926, pp. 10, 8 figs. Investigation covers study of two groups of iron-nickel alloys, first containing 35.5 per cent of nickel and second 38 per cent of nickel with varying additions of manganese and magnesium; coefficients of expansion between 20 and 100 deg. Cent. and up to 625 deg. Cent. have been determined; these alloys still require small additions of magnesium for ready forgeability; effects of nickel and manganese indicated by earlier workers are confirmed; additions of either or both, increase coefficient of expansion; effect of heat treatment is also indicated; annealing causes decrease in length while quenching produces increase; on other hand, annealing raises coefficient of expansion while quenching lowers it.

IRON - NICKEL. The Relation Between Space-Lattice Constant and Density of Iron-Nickel Alloys, A. Osawa. Tohoku Imperial Univ.—Sci. Reports, vol. 15, no. 3, July 1926, pp. 387-398, 6 figs. Investigation for purpose of examining relation between lattice constant and density, with view to ascertaining whether density of concentration of nickel is explained by variation in lattice constant, especially in case of reversible nickel iron.

HEAT-TREATMENT LABORATORIES. Heat Treatment Industrial Laboratories. Metal Industry (Lond.), vol. 29, no. 13, Sept. 24, 1926, pp. 290-291, 2 figs. Methods and equipment of laboratory of city of Birmingham Gas Department, England; details of recuperator furnaces and temperature recorders; research work; demonstrations on commercial scale of hardening, tempering, case-hardening, or normalizing.

METALLOGRAPHIC. Wheel Makers Expand Laboratory, R. A. Fiske. Iron Age, vol. 118, no. 13, Sept. 23, 1926, pp. 838-840, 4 figs. Test specimens studied in new metallographic department of Assn. of Manufacturers of Chilled Car Wheels; laboratory is located at plant of Griffin Wheel Co., Chicago, where facilities of chemical laboratory are available to supplement photomicrographing and physical testing equipment owned by Association.

MALLEABLE IRON

BLACK-HEART. Black-Heart Malleable (Remarques sur la malléable a cœur noir), C. Kluytmans. Fonderie Moderne, vol. 20, Sept., 1926, pp. 209-214, 12 figs. Discusses defects of black-heart malleable produced in reverberatory furnace, originating in crude metal of casting, and in annealing, and gives samples.

BLACK-HEART. The Embrittlement of Black-Heart Malleable Iron Resulting from Heating Overstrained Material, R. D. Allen, Am. Soc. for Steel Treating—Trans., vol. 10, no. 4, Oct., 1926, pp. 630-637, 6 figs. Presents entirely new developments in analyzing sensitive nature of black-heart malleable iron to brittleness (characterized by white fracture); author advances explanation of causes which have been found to contribute to this difficulty, and prescribes heat treatment which may be applied to reclaim original qualities of malleable iron that is known to have been subjected to conditions conducive to brittleness.

PROPERTIES. A Study of Malleable Cast Iron, O. Quadrat and J. Koritta. Am. Foundrymen's Assn.—Preprint no. 21, for mtg. Sept. 27-Oct. 1, 1926, 7 pp. Investigation to examine influence of temper carbon on physical properties of gray heart of malleable castings; effect of low and high temperatures and to determine tensile strength of ferrite material containing grain of temper carbon. Also abstract in Foundry Trade Jl., vol. 34, no. 529, Oct. 7, 1926, p. 306.

REQUIREMENTS. What May Be Required of Malleable Cast Iron, H. A. Schwartz. Am. Foundrymen's Assn.—Advance Paper, no. 44, for mtg. Sept. 27-Oct. 1, 1926. 16 pp. What consumer desires; importance of physical requirements; quantitative description of physical properties; possible tests; yield point; machinability requirements; welded castings; heat treatment; question of chemical composition.

STRENGTH. Resistance of Malleable Iron to Repeated Impact Stresses and Comparison of Strength of Machined and Unmachined Malleable Castings, E. Touceda. Am. Foundrymen's Assn.—Preprint, no. 39, for mtg. Sept. 27-Oct. 1, 1926, 9 pp., 2 figs. Results of tests.

METALLURGY

BIBLIOGRAPHY. Research in Metallurgical Literature, R. Rimbach. Forging—Stamping—Heat Treating, vol. 12, no. 9, Sept., 1926, pp. 354-357. Outlines procedure to be followed in making research into metallurgical literature; gives list of periodicals and magazines as guide.

BUREAU OF STANDARDS RESEARCH. Research Work at Bureau of Standards, H. W. Gillett. Forging—Stamping—Heat Treating, vol. 12, no. 10, Oct., 1926, pp. 368-374, 13 figs. Reviews research activities of metallurgical division of Bureau of Standards for past year.

METALS

CORROSION FATIGUE. Corrosion Fatigue, A. P. Hague. Metallurgist (Supp. to Engineer, vol. 142, no. 3694), Oct. 29, 1926, pp. 152-154, 9 figs. As result of investigations carried out in Cammell Laird research laboratories, it would appear that corrosion fatigue is responsible for many cases of failure which in past have been labeled mysterious; deals with relationship of corrosion fatigue to failure of street-car and railway axles; there is reason to believe that pitting in many cases commences at minute non-metallic inclusions in steel.

CORROSION-RESISTING. Metals to Resist Corrosion or High Temperatures, H. J. French. Am. Electrochem. Soc.—Advance Paper, no. 5, for mtg. Oct. 7-9, 1926, pp. 47-79, 6 figs. Principal characteristics and typical applications of metals used industrially to resist high temperatures or corrosion; those considered include commercially pure copper, aluminum, lead, tin, silver, nickel and iron, and their alloys.

DILATOMETRIC ANALYSIS. Principles and Chief Applications of Dilatometric Analysis of Materials, A. Portevin and P. Chevenard. Am. Foundrymen's Assn.—Advance Paper, no. 22, for mtg. Sept. 27-Oct. 1, 1926, 43 pp., 34 figs. Thermal and physical analysis; superiority of dilatometric analysis; calculation of coefficient of expansion; application of dilatometric analysis.

FAILURE. Some Recent Researches and their Bearing on the Theory of Failure of Metals, H. J. Gough. Metallurgist (Supp. to Engineer, vol. 142, no. 3689), Sept. 24, 1926, pp. 132-133. Reviews researches made in last one or two years on nature of slip and examines to what extent various conclusions reached are in agreement; effect of slip on atomic structure, and nature of hardening under slip; author believes that results of recent researches have led to somewhat deeper insight into causes of failure of metals than was formerly possible.

MELTING AND MIXING. Melting and Mixing. Metallurgist (Supp. to Engineer, vol. 142, no. 3694), Oct. 29, 1926, pp. 146-147. Discusses question of need for repeated melting of certain alloys if satisfactory castings are to be obtained; refers to work of Carpenter and Edwards on copper-aluminum alloys, strongly confirming view that nothing is to be gained by remelting; suggests that difficulties which arise when metals melted together for first time are cast, may be due to presence of gases.

MOLTEN, HEAT OF MIXING. Heat of Mixing of Molten Metals (Untersuchungen über Mischungswärmen geschmolzener Metalle), A. Magnus and M. Mannheimer. Zeit. für physikalische Chemie, vol. 121, no. 3-4, June 10, 1926, pp. 267-288, 3 figs. Direct and indirect methods have been employed in study of heat changes on mixing molten lead and tin, zinc and tin, lead and cadmium, tin and cadmium, and bismuth and tin in various proportions.

PICKLING. Addition of Substances to Pickling Baths in the Metal Industries (Ueber Sparzusätze zu Beizbädern in der Metallindustrie), W. H. Creutzfeldt. Zeit. für anorganische u. allgemeine Chemie, vol. 154, June 6, 1926, pp. 213-219, 2 figs. Loss of weight of iron and steel plates, and increase in brittleness of wire, were determined after treatment under controlled conditions with sulphuric acid alone and with addition of various organic substances known to moderate its action; loss of weight was least when tar oil was added; many other organic substances retarded action of acid to smaller extent.

PLASTIC DEFORMATION. The Question of Plastic Deformation, H. Preussler. Blast Furnace and Steel Plant, vol. 14, no. 10, Oct., 1926, pp. 442-447, 17 figs. Author gives insight into character of plastic deformation; various observations and theories discussed; application to rolling, forging and pressing. Translated from Stahl u. Eisen.

PROPERTIES. Metals and Their Properties, T. Newton. Sheet Metal Worker, vol. 17, no. 17, Sept. 24, 1926, pp. 657-658. Manufacture of wrought iron and steel; lead; manganese; mercury; nickel; phosphorus; platinum; silver; tin; zinc.

SECONDARY. The Problem of Secondary Metals in World Affairs, F. W. Willard. Indus. & Eng. Chem., vol. 18, no. 11, Nov., 1926, pp. 1178-1182, 5 figs. Metal resources of world; economics of secondary metal recovery; possibilities.

STRESSES. Local Stresses. Metallurgist (Supp. to Engineer, vol. 142, no. 3694), Oct. 29, 1926, pp. 145-146. Discusses cases in which severe local stressing may occur, such as sharp corners, notches of any kind, and jointing of material; suggestion that local stresses due to riveting can be avoided by use of welded joints is at first sight attractive, but there are obvious compensating difficulties.

TENSILE TESTS. The Testing and Properties of Materials (Werkstoffprüfung und Werkstoffeigenschaften), G. Sachs. Zeit. des Vereines deutscher Ingenieure, vol. 70, no. 35, Aug. 28, 1926, pp. 1167-1169. Analysis and review of tensile test; author suggests that it will never be practically possible to isolate and to test separately various fundamental physical properties involved in idea of strength, even when this idea can be completely analyzed; meaning of results of test depends entirely upon nature of material; suggests that value of reduction of area at fracture as indication of plastic qualities of metal is not adequately appreciated; discusses question of arriving at something like a "figure of merit" in which results of tensile test might be summarized in single numerical value. See translated abstract in Metallurgist (Supp. to Engineer, vol. 142, no. 3689), Sept. 24, 1926, pp. 138-139.

NICKEL STEEL

CHARACTERISTICS. Characteristics of Alloy Steels. Am. Mach., vol. 65, no. 16, Oct. 14, 1926, p. 647. Reference-book sheet nickel and nickel-chromium steels.

NONFERROUS METALS

GERMAN STANDARDS. German Standards for Non-Ferrous Metals (Die deutschen Werkstoffnormen der Nichteisenmetalle), B. E. Sauerbrey. Dinglers polytechnisches Jl., vol. 341, no. 17, Sept., 1926, pp. 192-194. Summarizes standardization work applying to nickel, aluminum, tin, copper and alloys; rods, tubes, wire and sheet.

OIL FUEL

ATOMIZATION IN BURNERS. Factors Affecting Atomization in Oil Burners, J. F. Barkley. Power Plant Eng., vol. 30, no. 19, Oct. 1, 1926, pp. 1048-1049, 1 fig. Data secured and conclusions drawn from experiences with combustion of oil in power-plant furnaces.

BURNERS. Progress in Industrial Heating, L. MacLeod. West. Machy. World, vol. 17, no. 9, Sept., 1926, pp. 388-390, 5 figs. Details of Ray fuel-oil burning system, which is supplied with oil from independent pump set; applications of these burners to industry.

OPEN-HEARTH FURNACES

BASIC. The Basic Open-Hearth Charge, P. H. Shaeffer. Min. & Met., vol. 7, no. 238, Oct., 1926, pp. 433-435. Quality and proportion of components influence cost of product; relation of light and heavy scrap to iron charge for desired carbon content.

LOW-SULPHUR BASIC STEEL. Action of Sulphur in Basic Open-Hearth Steel Practice, A. N. Diehl. Am. Iron & Steel Inst.—Advance Paper, for mtg. Oct. 22, 1926, 37 pp., 14 figs. Results of investigation; influence of pig iron and scrap; influence of fuel; limestone, iron ore and refractories, manganese, gases and temperature and of slag. See also abstract in Iron Age, vol. 118, no. 18, Oct. 28, 1926, pp. 1196-1197.

MANGANIFEROUS ORES, USE OF. The Use of High-Manganese Basic Pig Iron and Manganiferous Ores in Open-Hearth Steel Practice, A. W. Smith. Am. Iron & Steel Inst.—Advance Paper for mtg. Oct. 22, 1926, 8 pp. Discusses reasons which have been advanced against use of manganiferous pig iron in open-hearth practice; advantages obtained by using manganiferous pig iron; in author's opinion advantages of use of manganiferous pig iron are greater than disadvantages; use of 4 per cent manganiferous fine ore as charged ore; use of manganiferous lump ore as working ore. See also abstract in Iron Age, vol. 118, no. 18, Oct. 28, 1926, pp. 1193-1194.

OXYACETYLENE WELDING

ALLOY STEELS. Gas Welding Alloy Steels, W. Stewart. Welding Engr., vol. 11, no. 10, Oct., 1926, pp. 41-42. Points out that all alloys can be welded; heat treatment of welds; brazing alloy steels; why some bronze welds fail; use of cast-iron filler rod; experience with welded bits.

COPPER. Oxy-Acetylene Welding of Copper, A. Eyles. Machy. (N. Y.), vol. 33, no. 3, Nov., 1926, pp. 199-200, 3 figs. Precautions necessary in welding of copper; preparing copper for welding; torch and flame adjustment.

RERIGERATING INDUSTRY. Oxy-Acetylene Welding in Refrigerating Work, J. W. Catalene. Refrigeration, vol. 40, no. 4, Oct., 1926, pp. 64-65. Strength and tightness essentials; welding of freezing-tank coils; underground pipe lines; welding replaces soldering of ice cans; castings cut by flame. (Abstract). Paper read before Nat. Assn. of Practical Refrigerating Engrs.

ROOF TRUSSES. Tests on Oxwelded Roof Trusses, H. H. Moss. West. Machy. World, vol. 17, no. 10, Oct., 1926, pp. 437-439 and 448, 5 figs. Application of engineering principles and procedure control in welding of structural steel.

PYROMETERS

SURFACE-TEMPERATURE MEASUREMENTS. Pyrometers for Surface Temperature Measurements. Engineering, vol. 122, no. 3171, Oct. 22, 1926, pp. 507-508, 3 figs. New form of pyrometer patented by Cambridge Instrument Co., London, which has been successfully employed on calendaring bowls, paper making rollers, vulcanizing-press platens, rubber-press rollers and other similar machines; instruments are of thermoelectric type.

RAILS

WEAR. The Wear of Rails (Ein Betrag zur Frage des Verschleisses der Eisenbahnschienen), A. Dormus. Stahl u. Eisen, vol. 46, no. 28, July 15, 1926, pp. 948-952. Based on experience on Arlberg and Meran-Bozen lines, it is shown that basic-steel rails having tensile strength of 88 kg. per sq. mm. were far more durable than different other types employed, having tensile strength of only 45 to 50 kg. per sq. mm.; these conclusions from actual service records are totally opposed to results obtained in series of abrasion tests made with Spindel machine, which author regards as evidence that values given by this machine bear no relation to abrasion resistance in service, and suggests explanation. See translated abstract in Metallurgist (Supp. to Engineer, vol. 142, no. 3689), Sept. 24, 1926, pp. 135-136.

REFRACTORIES

FOUNDRY. Foundry Refractories, M. C. Booze. Fuels & Furnaces, vol. 4, no. 9, Sept., 1926, pp. 1071-1076. Discusses conditions imposed on refractories in foundry furnaces, namely, abrasion, flame, impingement and expansion, and wall construction; insulation, effect of joints, wall thickness and heat capacity; specifications and method of testing.

Joint Committee on Foundry Refractories, Am. Foundrymen's Assn.—Advance Paper, no. 43, for mtg. Sept. 27-Oct. 1, 1926, 53 pp. Preliminary reports of subcommittees on survey of refractories in malleable steel and non-ferrous foundries.

FUSED OXIDES. The Thermal Expansion of Some Fused Oxides Used as Refractories, G. E. Merritt. Am. Electrochem. Soc.—Advance Paper, no. 22, for mtg. Oct. 7-9, 1926, pp. 283-291, 10 figs. Thermal expansion of oxides of silicon, thorium and zirconium, of mixture of one-to-one molecular proportions of thoria and zirconia, and of refractories made of magnesia, alumina and zirconia were measured.

INDUCTION FURNACES. Refractories for Induction furnaces, M. Unger. Am. Electrochem. Soc.—Advance Paper, no. 4, for mtg. Oct. 7-9, 1926, pp. 41-46, 3 figs. Requisites for commercial furnace lining of induction furnaces; of various materials studied, magnesium oxide proved to be one refractory more nearly fulfilling conditions than any other; pitch was selected as best bounding material.

MELTING PURE METALS, FOR. Refractories for Melting Pure Metals: Iron, Nickel, Platinum, L. Jordan, A. A. Peter-

son and L. H. Phelps. Am. Electrochem. Soc.—Advance Paper, no. 8, for mtg. Oct. 7-9, 1926, pp. 115-124. Investigation carried out by Bureau of Standards on refractory materials best suited for melting of pure iron, nickel and platinum metals.

RECRYSTALLIZED SILICON CARBIDE. An application of recrystallized Silicon Carbide, F. A. J. Fitzgerald. Am. Electrochem. Soc.—Advance Paper, no. 21, for mtg. Oct. 7-9, 1926, pp. 279-282, 1 fig. Describes use of recrystallized silicon carbide as refractory material under certain special chemical and physical conditions.

TEMPERATURE MEASUREMENT. Temperature Measurement of Refractories during a Load Test (Die Temperaturmessung beim Druckerweichungsversuch an feuerfesten Baustoffen), W. Miehr. Tonindustrie-Zeitung, vol. 50, no. 32, April 24, 1926, pp. 563-567, 4 figs. Softening temperature of same refractory varied from 1360 to 1403 deg. cent. depending upon methods used for measuring temperature.

ROLLING MILLS

COLD STRIP ROLLING. Cold Rolling Mill for Broad Strips (Kaltwalzmalfchinen für breite Bänder). Kruppsche Monatshefte, vol. 7, Aug., 1926, pp. 140-144, 9 figs. Describes sets of Krupp machines for brass and copper strips, including bending, reversing and reeling machines, circular strip shears, etc.

COPPER WIRE. Copper Wire Worked at High Speed, R. A. Fiske. Iron Age, vol. 118, no. 16, Oct. 14, 1926, pp. 1055-1059, 7 figs. Practice in new copper-rod and wire mill of Western Elec. Co. at Hawthorne Works, Chicago; 75 seconds from time billet enters first groove of roughing mill 220-lb. coil of ¼-in. copper rod on its way to pickling baths; later, this rod is drawn at finishing speed of 2000 ft. per min. to various sizes.

ELECTRIFICATION. Electrifies Rolling Mill Drives. Iron Trade Rev., vol. 79, no. 19, Nov. 4, 1926, pp. 1167-1169, 4 figs. Change-over program of Inland Steel Co., Indiana Harbor, Ind., is accomplished in minimum time despite obstacles encountered; motor now in use for 36-in. blooming mill was built by Westinghouse Electric & Mfg. Co., and is rated at 7000 hp.; 24-in. bar mill is driven by General Electric reversing motor rated at 3000 hp.; 24-in. billet and sheet bar mill driven by 3000-hp. induction motor.

EXPERIMENTAL. Experimental Rolling Mills at the Technical High School at Breslau, Germany (Das Versuchswalzwerk der Technischen Hochschule Breslau). Stahl u. Eisen, vol. 46, no. 29, July 22, 1926, pp. 986-987, 2 figs.; also translated abstract in Metallurgist (Supp. to Engineer, vol. 142, no. 3689), Sept. 24, 1926, p. 139. New installation consists of mill having roll diameters of 450 mm. and length of 800 mm., driven by electric motors developing 75 hp. at 220 volts, speed being variable between 600 and 750 r. p. m.; it is well equipped with subsidiary appliances, including furnaces, both gas-fired and electric, special machine tools and hydraulic press; primary object of plant seems to be study of rolling process itself.

MANIPULATORS, BLOOMING MILLS. Manipulators for Blooming Mills, L. Iverson. Iron and Steel Engr., vol. 3, no. 10, Oct., 1926, pp. 437-439, 3 figs. Ideal manipulator is one which can perform required operations of pushing, turning and grasping ingot or bloom in minimum of time, with least attention for upkeep and repairs; solution of problem as it has been accomplished by Mesta Machine Co.

MANIPULATORS, BLOOMING MILLS. Manipulators for Two High Reversing Blooming Mill, C. J. Klein. Iron & Steel Engr., vol. 3, no. 10, Oct., 1926, pp. 439-441 and (discussion) 441-443. Design of manipulator must be such that there is practically no cause for breakdown, or if such would occur, it could be readily fixed with least possible delay; traces developments and describes general design of up-to-date manipulators.

MERCHANT. The New Gautier Mills at Johnstown, G. A. Richardson. Blast Furnaces & Steel Plant, vol. 14, no. 10, Oct., 1926, pp. 416-422, 12 figs. New merchant mills of Bethlehem Steel Co. at Johnstown, represent most modern in rolling mill-equipment; complete safety protection provided.

ROLLING, THEORY AND PRACTICE OF. The Theory and Practice of Rolling Steel, W. Tafel. Iron Trade Rev., vol. 79, nos. 2, 4, 6 and 8, July 8, 22, Aug. 5 and 19, 1926, pp. 76-79, 196-199, 313-315, 436-437 and 446, 22 figs. July 8: Rolled cast designs. July 22: Considerations to be used for so-called ornamental iron, which is type of periodic profile; complex profiles. Aug. 5: Power required for rolling; how to determine work; determination to relation of rolling passes to total working time. Aug. 19: Use of gas-steam engines for rolling-mill drive.

PLATE MILLS. Plate Mills—Recent Developments and Tendencies, F. M. Gillies. Am. Iron & Steel Inst.—Advance Paper, for mtg. Oct. 22, 1926, 16 pp. Most outstanding of recent improvements is electric drive and use of electrical equipment in general mill work; improvement in design and layout of buildings used in manufacture of plate; advancement in heating end of mill has been more in kinds of fuels burned and methods of burning them than in design of furnaces; development and principle of handling material; shearing developments; tendencies toward specialization. See also abstract in Iron Age, vol. 118, no. 18, Oct. 28, 1926, pp. 1197-1198.

SEAMLESS-TUBE MANUFACTURE. Make 50-Ft. Tubes From Ingots. Iron Age, vol. 118, no. 13, Sept. 23, 1926, pp. 846-850, 11 figs. Seamless-tube plant at Allenport, Pa., embraces one piercing mill and two pilger mills; reheating and polishing feature finishing operations.

SHEET AND TIN. Sheet and Tin Mill Well Planned, R. A. Fiske. Iron Age, vol. 118, no. 16, Oct. 14, 1926, pp. 1062-1065, 5 figs. Producing capacity of Chicago district in sheets and tin plate has been increased 9000 to 10,000 net tons per month through completion of new mill by Youngstown Sheet and Tube Co. at Indiana Harbor, Ind.; simplicity of equipment layout and straight-line movement of material feature new plant.

SPAIN. Modern Steel Plant at Sagunto, Spain, C. A. Raunick. Elec. World, vol. 88,

no. 14, Oct. 2, 1926, pp. 691-694, 3 figs. Consists of completely electrified blooming mill, structural mill and plate mills, power house and substation; electrical equipment comprises more than 90 motors totaling over 16,000 hp.

STRIP MILLS. Strip Mill is Unusually Compact, F. L. Prentiss. Iron Age, vol. 118, no. 17, Oct. 21, 1926, pp. 1127-1128, 3 figs. Floor space is conserved in plant of Cleveland Cold Rolling Mills Co.; accurate adjustment of mill rolls and reversible coilers are features; plant was built for special purpose of supplying prompt service in narrow sizes of cold-rolled strip steel to users in Cleveland territory.

STAYBOLTS

SPECIAL STEELS FOR. Locomotive Firebox Stay Bolts. Metallurgist (Supp. to Engineer, vol. 142, no. 3689), Sept. 24, 1926, pp. 141-142. Refers to experiment recently carried out on Detroit, Toledo & Ironton R. R. of Henry Ford, making use of alloy steel containing 0.10 to 0.14 per cent of carbon and 0.25 to 0.35 per cent of chromium; apparently these bolts have successfully resisted corrosion and erosion on flame side; success of American experiment would suggest trial of one or other of new steels for staybolt purposes.

STEEL

BOILER, INTERCRYSTALLINE CRACKS. A New Boiler Steel and Intercrystalline Cracks. Power, vol. 64, no. 17, Oct. 26, 1926, p. 623. Experiments with new boiler steel and cause of intercrystalline cracks were discussed at two meetings recently held in Europe, that of Association of Steam Boiler Inspectors at Zürich, Switzerland, and that of Association of Large Steam Boiler Plants at Cassel, Germany.

CAUSTIC EMBRITTLEMENT. Caustic Embrittlement of Steel, S. W. Parr and F. G. Straub. Chem. and Met. Eng., vol. 33, no. 10, Oct. 1926, pp. 604-607, 6 figs. Study of its cause and prevention in boilers reveals valuable data for other chemical engineering applications.

CEMENTATION. Rational Use of Cements (L'emploi rationnel des céments), J. Herbert. Technique Moderne, vol. 18, nos. 16 and 17, Aug. 15 and Sept. 1, 1926, pp. 481-491 and 525-532, 40 figs. Aug. 15: Practical results of systematic study of cementation: reactions; carbons used, composition of cements, action of various constituents; tests in cementation with charcoal, alone or in combination. Sept. 1: Composition and distribution of zones of cementation; cements used in form of pastes; resistance of some steels to cementation.

CORROSION. Determining Rapidity of Rusting in High-Grade Steels (Ermittlung Rostgeschwindigkeit von Qualitätsstählen), V. Duffek. Korrosion und Metallschutz, vol. 2, nos. 7-8, July-Aug., 1926, pp. 183-187, 5 figs. Discusses cause of corrosion and tests to determine its rapidity by increasing pressure of oxygen; process of corrosion, effect of quantity and form of rust on rapidity of formation.

CORROSION. Tests as to Exact Determination of Corrosion of Steels by Chemical Reagents (Versuche über die genaue Bestimmung der Korrosion durch chemische Agentien an Stählen), V. Duffek. Korrosion und Metallschutz, vol. 2, no. 6, June, 1926, pp. 149-152, 3 figs. Describes method depending on reduction in weight of steel when suspended in acids for 24 hours, passivity of steel; effect of surface conditions on velocity of dissolution.

FATIGUE TESTS. Some Comparative Fatigue Tests in Special Relation to the Impressed Conditions of Test, H. J. Gough and H. J. Tapsell. Aeronautical Research Committee—Reports and Memoranda, no. 1012, Apr., 1926, 21 pp. Results of lengthy series of endurance tests on two steels adopted by Aeronautical Research Committee as standard material for comparative tests by various investigators; it is shown that varying results obtained can not be reconciled on any simple basis, such as criterion of limiting shear stress.

GASES IN. The Determination of Gases in Iron and Steel (Die Bestimmung der Gase in Eisen und Stahl), P. Klinger. Stahl u. Eisen, vol. 46, nos. 37, 38 and 39, Sept. 16, 23 and Oct. 7, 1926, pp. 1245-1254, 1284-1288 and 1353-1356 and (discussion) 1356-1358, 4 figs. Review of published works on subject; hot extraction in vacuum and evaluation of results; critical discussion of chemical-change processes; solubility of CO and CO_2 in iron; conclusions.

HARDNESS. A Further Study of the Distribution of Hardness in Quenched Carbon Steels, and Quenching Cracks, T. Kase. Tohoku Imperial Univ.—Sci. Reports, vol. 15, no. 3, July, 1926, pp. 371-386, 21 figs. Investigation of distribution of hardness in carbon steels, which had been quenched, or quenched and immersed in liquid air, hardness measurement being made by means of Shore's scleroscope. (In English).

PHOSPHORUS ELIMINATION. Eliminating Phosphorus, Sulphur and Oxygen in Ferrous Metallurgy (La teoria dell'eliminazione del fosforo dello zolfo e dell'ossigeno in siderurgia), A. Angiolani. Industria, vol. 40, no. 5, Mar. 15, 1926, pp. 116-119. Discusses various reactions, calculates required temperatures; also furnace linings necessary.

SALT SOLUTIONS, EFFECT OF. Action of Solutions of Salts on Ferrous Metals (L' action des solutions salines sur les métaux ferreux), R. Girard. Académie des Sciences—Comptes Rendus, vol. 183, no. 3, July 19, 1926, pp. 213-214. Examination of action on steel and cast iron of solutions of salts of concentrations approximately the same as those at which they are present in sea water; magnesium chloride and magnesium sulphate are relatively active, and attack steel more rapidly than cast iron, but in no case does rusting occur; with calcium sulphate a protective coating of rust is formed.

SPARK ANALYSIS (Apercu sur l' essai aux étincelles), E. Pitois. Bulletin Technique du Bureau Veritas, vol. 8, no. 8, Aug., 1926, pp. 151-153, 6 figs. Describes sparks produced by contact of steel with grindstone, etc., and shows that quality of steel may be determined from figure of spark.

SPECIFIC HEAT. On the Specific Heat of Carbon Steels, S. Umino. Tohoku Imperial Univ.—Sci. Reports, vol. 15, no. 3, July, 1926, pp. 331-369, 14 figs. Results of experiments made by author to determine heat content of each temperature within

range from 100 to 1250 deg. cent.; specific heat of carbon steels with reference to carbon concentration and heat of transformation from specific heat-temperature curve. (In English).

STAINLESS. Stainless Steels and Iron, A. C. Yorke. Metal Industry (Lond.), vol. 29, no. 18, Oct. 29, 1926, pp. 419-420. Cutlery qualities; composition of slag; rolling, annealing, pickling, welding, uses and costs.

TENSION AND COMPRESSION, EFFECT OF. On the Change of Temperature and Magnetic Induction of Steel in Tension and Compression Test, Y. Kidani and R. Sasaki. Tokyo Imperial Univ., Faculty of Eng.—Jl, vol. 16, no. 11, Oct., 1926, pp. 237-240, 11 figs. Experiments to determine heat evolution or absorption, and change of magnetic induction of initially magnetized or demagnetized carbon steels when they undergo elastic or plastic deformation. (In English.)

STEEL CASTINGS

ANNEALING. Annealing Steel Castings, L. J. Barton. Foundry, vol. 54, no. 21, Nov. 1, 1926, pp. 854-857, 6 figs. Specifications for steel castings require some kind of heat treatment; this is necessary that castings may be relieved of strains and meet physical tests specified.

CONVERTER PROCESS. Some Physical Properties and Composition of Cast Converter Steel, C. M. Campbell. Am. Foundrymen's Assn.—Preprint no. 37, for mtg. Sept. 27-Oct. 1, 1926, 6 pp. Author presents tension-test figures and composition of several heats of cast carbon steel made by converter process; calls attention to high ductility obtained from test bars "as cast" and in annealed condition, also close limits within which it is possible to hold composition of various kinds of carbon steels; discusses low limits within which it is possible to hold sulphur in converter.

MANGANESE IN. Manganese in Cast Steels, J. H. Hall. Am. Foundrymen's Assn.—Preprint, no. 40, for mtg. Sept. 27-Oct. 1, 1926, 16 pp., 4 figs. In author's opinion, results of tests fully justify opinion that heat-treated cast steels containing from .20 per cent to .30 per cent carbon, and manganese from 1 to 2 per cent, possess remarkable combination of properties that makes them of greatest value for severe service in machine parts.

STEEL, HEAT TREATMENT OF

ANNEALING. The Heat Treatment of Steel, H. M. Boylston. Fuels and Furnaces, vol. 4, no. 9, Sept. 1926, pp. 1035-1066, 22 figs. Annealing of forged or rolled carbon-steel objects, of cold-worked objects, steel castings, and tool-steel, high-speed steel and special steels; furnaces for annealing; toughening treatments, hardening, tempering, carburizing and case hardening; heat treatment of case-hardened objects.

ELECTRIC. Electric Equipment Reduces Dodge Heat-Treating Costs, W. L. Carver. Automotive Industries, vol. 55, no. 17, Oct. 21, 1926, pp. 686-689, 6 figs. Furnaces in both carburizing and heat-treating departments are electrically heated and major portion of handling work is done by electrically operated machinery; heat loss low.

FERRO-CARBON-TITANIUM. Treatment of Steel with Ferro-Carbon-Titanium, G. F. Comstock. Foundry Trade Jl., vol. 34, no. 524, Sept. 2, 1926, pp. 205-207. Shows what is being done with ferro-carbon-titanium at present time and gives outline of practical results obtained by its use; use of titanium in steel for sand castings; value of ferro-carbon-titanium lies in its being good deoxidizer; more powerful qualitatively than silicon and one that does not make steel dirty when used; it is essentially gray cast iron containing titanium-carbide, as well as some dissolved titanium, and is made in electric-arc furnace by reduction of oxide ore with carbon. Paper read before Stockholm meeting of Iron & Steel Inst.

NORMALIZING AND ANNEALING. Normalizing and Annealing. Machy. (Lond.), vol. 28, no. 729, Sept. 30, 1926, pp. 791-792. Points out that normalizing is very much simpler and cheaper process than oil quenching and tempering; there is only one heating instead of two, and there is not vital necessity for extreme accuracy of temperature control; when annealing proper is substituted for normalizing it is possible that very much worse structure is result.

PRINCIPLES. Facts and Principles Concerning Steel and Heat Treatment, H. B. Knowlton. Am. Soc. for Steel Treating—Trans., vol. 10, no. 4, Oct., 1926, pp. 638-656, 11 figs. Fundamental principles of normalizing, annealing, hardening, tempering and heat treating of low and medium carbon steels; use of critical-range diagrams and charts giving physical properties produced by different heat treatments, are explained; photomicrographs are given to show effects of different heat treatments upon structure of steel.

STEEL INDUSTRY

RUSSIA. The Russian Iron and Steel Industry. Iron & Coal Trades Rev., vol. 113, no. 3052, Aug. 27, 1926, p. 295. Statistics of production.

SWEDEN. The Development of the Swedish Iron Industry During the Last Thirty Years, A. Johansson and A. Wahlberg. Iron & Coal Trades Rev., vol. 113, nos. 3052 and 3053, Aug. 27 and Sept. 3, 1926, pp. 291-294 and 351-353. Presents idea of what has been done in Sweden during last thirty years in developing iron industry; deals with raw materials, pig-iron production, wrought iron and steel, mechanical treatment of iron and steel; annealing of steel; metallurgical education; market for Swedish iron and steel.

STEEL MANUFACTURE

BASIC. Influence of Substance and Duration of Charge on Heat Balance and Temperature of a Thomas Charge (Einfluss der Stoffe und der Chargendauer auf Wärmebilanz und Temperaturverlauf einer Thomascharge), H. Bansen. Stahl u. Eisen, vol. 46, no. 38, Sept. 23, 1926, pp. 1277-1283 and (discussion) 1283-1284, 3 figs. Thermal conditions in the Thomas process; substance and heat balance; evaluation of different materials for charge; influence of temperature on bath.

DYNAMO SHEET STEEL. The Production of Dynamo Sheet-Steel at the Verkh-Issetsk Iron Works, N. J. Epiphanon. Electritchestvo, no. 7, July, 1926, pp. 318-321.

2 figs. Results of tests on dynamo steel being carried out at Ural Iron Works and comparison with results of tests in other countries. (In Russian.)

FORGING STEEL. Manufacture of Forging Steel by the Basic Open-Hearth Process, R. L. Cain. Am. Inst. Min. & Met. Engrs. —Trans., no. 1591-C, for mtg. Oct., 1926, 6 pp., 2 figs. Deals with character of charge, working heat, tapping heat and ladle additions, teeming and metallurgy.

STRIP STEEL. Manufacturing Strip Steel. Can. Machy., vol. 36, no. 9, Aug. 26, 1926, pp. 15-16, 7 figs. Hot-rolling process in manufacture of strip steel as practiced in mill of Stanley Works, New Britain Conn.

STRUCTURAL STEEL

CORROSION. Corrosion of Structural Steel, F. N. Speller. Am. Iron & Steel Inst. —Advance Paper, for mtg. Oct. 22, 1926, 20 pp., 4 figs. Discusses framework of steel structures, such as bridges and steel frame buildings; mechanism and classification of corrosion; influence of composition; preventative measures. See also abstract in Iron Age, vol. 118, no. 18, Oct. 28, 1926, pp. 1200-1201.

WELDING

APPLICATIONS. Modern Welding Methods (Neuere Schweissverfahren und Gestaltung), W. Strelow. Zeit. des Vereines deutscher Ingenieure, vol. 70, no. 40, Oct. 2, 1926, pp. 1317-1323, 19 figs. Comparison of welded and riveted joints and their strength properties, based on experiments and practical experience; examples are given showing applications of welding to building construction, tank construction, shipbuilding, car and machine construction, and resulting simplifications in design.

FILLER RODS. Observation Testing of Filler Rods, J. B. Green. Welding Engr., vol. 11, no. 10, Oct., 1926, pp. 50-52. Method of testing which permits welder to determine in rough way operating characteristics and weld properties.

FUSION. Essentials in Fusion Welding, S. W. Miller. Am. Welding Soc.—Jl. vol. 5, no. 9, Sept., 1926, pp. 8-10. Matters that must be given careful attention are design, materials, methods, supervision, training and testing.

HIGH-CHROMIUM ALLOYS. Welding High-Chromium Aloys, S. M. Norwood. Brass World, vol. 22, no. 10, Oct., 1926, pp. 327-328. Brittleness of alloys containing more than 10 per cent chromium serious problem; addition of 8 per cent nickel improves alloy; other additions suggested.

IRON AND STEEL. Welding of Iron and Steel, C. A. Adams. Am. Iron & Steel Inst.—Advance Paper, for mtg. Oct. 22, 1926, 71 pp., 51 figs. Discusses different processes of welding; their advantages, limitations and fields of usefulness with particular reference to welding of iron and steel. See also abstract in Iron Age, vol. 118, no. 18, Oct. 28, 1926, pp. 1194-1196.

JIGS AND FIXTURES. Saving Money by Welding Jigs and Fixtures, R. E. Kinkead. Am. Mach., vol. 65, no. 18, Oct. 28, 1926, pp. 707-708, 7 figs. Both time and expense of making patterns can be saved and cheaper material can be used in body of fixture.

LOCOMOTIVE PARTS. Welding of Locomotive Parts by the Oxyacetylene, Electric, and Thermit Processes, G. H. Gjertsen. Am. Welding Soc.—Jl., vol. 5, no. 10, Oct., 1926, pp. 22-29, 8 figs. In railway work, thermit is almost entirely limited to welding of engine frames, whereas oxyacetylene and electric arc cover much the same field in welding of many of steel parts.

UNIVERSITY CURRICULA. Welding Science in the Engineering Curriculum of Universities. Am. Welding Soc.—Jl., vol. 5, no. 10, Oct., 1926, pp. 8-19. Contains three articles by S. T. Hart, O. D. Rickly and W. P. Turner, respectively, telling what is being done in American universities to study science of welding and what they have in mind to do in near future.

WIRE

ANNEALING. Annealing Wire in Salt Baths, A. E. Bellis. Wire, vol. 1, no. 7, Nov., 1926, pp. 223-225 and 245-249, 2 figs. Characteristics of liquid salt baths in heat treatment of wire.

MANUFACTURE. The Manufacture of Steel and Iron Wire in Germany, H. Altpeter. Wire, vol. 1, no. 6, Oct., 1926, pp. 194-195 and 212, 4 figs. Types of furnaces and lead baths for heat treatment of wire. Translated from Stahl u. Eisen. See reference to original article in Eng. Index, 1925, p. 785.

STEEL. The Manufacture of Iron and Steel Wire in Germany, H. Altpeter. Wire, vol. 1, no. 7, Nov., 1926, pp. 230-231, 243 and 249, 2 figs. Heat treatment of spring and music wire. Translated from Stahl u. Eisen.

WROUGHT IRON

DEVELOPMENTS. Trend of Development in the Wrought Iron Industry, J. Aston. Am. Inst. Min. & Met. Engrs.—Trans., no. 1595-C, for mtg. Oct., 1926, 13 pp. Early progress; points out that puddling practice has not advanced; demand for wrought iron; definition of wrought iron; review of processes employed; process developed by author, which so nearly parallels steel-making that operating costs should be closely in line.

NOTE. — The abbreviations used in indexing are as follows:

Academy (Acad.)
American (Am.)
Associated (Assoc.)
Association (Assn.)
Bulletin (Bul.)
Bureau (Bur.)
Canadian (Can.)
Chemical or Chemistry (Chem.)
Electrical or Electric (Elec.)
Electrician (Elecn.)
Engineer (Engr.[s])
Engineering (Eng.)
Gazette (Gaz.)
General (Gen.)
Geological (Geol.)
Mining (Min.)
Heating (Heat.)
Industrial (Indus.)
Institute (Inst.)
Institution (Instn.)
International (Int.)
Journal (Jl.)
London (Lond.)
Machinery (Machy.)
Machinist (Mach.)
Magazine (Mag.)
Marine (Mar.)
Materials (Matls.)
Mechanical (Mech.)
Metallurgical (Met.)
Municipal (Mun.)
National (Nat.)
New England (N. E.)
Proceedings (Proc.)
Record (Rec.)
Refrigerating (Refrig.)
Review (Rev.)
Railway (Ry.)
Scientific or Science (Sci.)
Society (Soc.)
State names (Ill., Minn., etc.)
Supplement (Supp.)
Transactions (Trans.)
United States (U. S.)
Ventilating (Vent.)
Western (West.)

News of the Chapters

STANDING OF THE CHAPTERS

IN the following tabulation there appears the relative membership standing of the 28 chapters and 3 groups of the Society as of December 1, 1926:

GROUP I		GROUP II		GROUP III	
1. Cleveland	403	1. Lehigh Valley	137	1. Montreal	83
2. Chicago	380	2. Hartford	135	2. Los Angeles	73
3. Detroit	377	3. Milwaukee	128	3. New Haven	71
4. Philadelphia	352	4. Golden Gate	117	4. Washington	68
5. Pittsburgh	320	5. Syracuse	95	5. Tri-City	65
6. New York	268	5. Cincinnati	95	5. Rockford	65
7. Boston	242	7. Indianapolis	84	7. Rochester	64
		8. St. Louis	83	8. Worcester	59
		9. Buffalo	59	9. Toronto	58
		10. Northwest	55	10. Schenectady	49
				11. Providence	43
				12. Fort Wayne	39
				13. Springfield	33
				14. Southern Tier	32

There were 126 new and reinstated members during the month of November. During this period 28 names have been dropped for non-payment of dues and 13 have been dropped on account of resignation and deaths, leaving a net gain for the month of December of 85 members.

On December 1, 1926, the total membership of the Society was 4302.

GROUP I—The Cleveland Chapter gained 2 members while the Chicago Chapter made a gain of 4 members during the month. The Detroit Chapter made the largest gain of any of the chapters in Group I, adding 19 to their roll. With this large increase in membership, they jumped from 4th to 3rd place, right on the heels of Chicago. All but 2 of the chapters in Group I showed gains for the month of November.

GROUP II—The relative standing of the chapters in Group II remains the same as during the month of October. However, there have been several changes in their numerical standing. Lehigh Valley and Golden Gate were the two chapters of this group which showed a small loss for the month.

GROUP III—The Montreal Group showed the greatest gain in membership of all chapters and groups for the month, with a gain of 25 members, advancing them from position 7 to 1st place, incidentally increasing their membership by 43%. This surely is a remarkable gain for one of our newest groups. All the other chapters and groups retain their same relative positions as last month; however, there has been some slight change in their numerical rating.

It will be noted that there is a new member in Group III—the Southern Tier Group, with a membership of 32. Announcement of this new group appears on page 837 of this issue of TRANSACTIONS.

BOSTON CHAPTER

The November meeting of the Boston Chapter was held at the Fore River Plant of the Bethlehem Shipbuilding Corporation at Quincy, Mass., on Friday, November 5, 1926, when about seventy-five members spent the afternoon going through the various departments of the plant. The departments visited included the machine shop tool room, hardening room, foundry, plate fabricating department, forge and boiler shops, and some of the interesting operations were the making of a high silicon aluminum alloy casting, hardening of rivet sets and other shipbuilding tools, special drop forging operations with automatic pyrometer control on the heating furnaces, galvanizing of steel sheets, and the bending and shaping of copper and steel pipe and plates.

At four o'clock, the party was the guest of the United States Navy, having been granted permission to go aboard the new aeroplane carrier "Lexington" by the secretary of the navy, Honorable Curtis D. Wilbur, and the trip through the various parts of the ship was conducted by the Naval officers in charge of construction. This great 33,000-ton ship, having a length of 888 feet and an upper deck with two acres of open space for landing aeroplanes, gave the members a chance to see some of the great accomplishments of the navy and the problems with which they are confronted in a task of this kind.

At five o'clock, the members assembled in the Conference Room and were addressed for a few minutes by H. E. Gould, general superintendent, who, after a few words of welcome, gave a short talk on the history of the plant and its predecessor, the Fore River Ship Yard. G. A. Richardson, manager of technical publicity for the Bethlehem Steel Corporation, then presented several reels of motion pictures showing the "Manufacture of Sheet and Tin Plate" at their Sparrows Point Plant, near Baltimore.

Dinner was served in the main dining room at 6:30, after which the secretary's report of the October meeting was given and the increase in membership announced. Following this order of business the speaker of the evening, Captain Louis Shane, United States Navy, in charge of naval construction at Fore River, was introduced by the chairman and delivered a talk on "Nonferrous Metals." Captain Shane's paper was particularly interesting in that it was really a story of his personal experience with nonferrous metals in naval construction and engineering during the thirty-two years he has spent in the service. His talk was confined almost wholly to 88-10-2 bronze and manganese bronze. In speaking of the 88-10-2 mixture, he stated that he was very partial to crucible melted against open-fire furnace melted bronze as, with few exceptions, the castings made by the crucible process, while possessing no better physical properties, were more free from segregation and stood a much greater hydraulic test. He recommended the use of pyrometers during the melting and suggested that the best pouring temperature was about 2300 degrees Fahr. He did not discuss electric melting. The discussion which followed had to do mostly with tin-base babbitt, in which a large number present appeared to be very much interested. Captain Shane said that the best all-round babbitt he had used in connection with his work on battleships was made up of 83.5 parts of tin, 5.5 parts of copper and 11.0 parts of antimony, best results being obtained when poured at 850-900 degrees Fahr. into parts which had been care-

fully tinned and preheated to about 400 degrees Fahr. He agreed with one of our members that an alloy of 85 per cent tin, 7.5 per cent. copper and 7.5 per cent antimony was a very good one for Diesel engine work.

A rising vote of thanks was tendered to Captain Shane for his interesting talk and to Mr. Gould and his associates for their hospitality.

This meeting was under the general direction of W. J. Kunkel, of the program committee, and arrangements for the visitation were very ably handled by E. B. Ashworth, superintendent of the forge shop, to whom the Chapter is indebted for the invitation to hold the meeting at the Fore River Plant.

H. E. Handy.

CINCINNATI CHAPTER

E. C. Bain, research metallurgist of The Carbide and Carbon Laboratories, New York, addressed the joint meeting of the American Society for Steel Treating and the Cincinnati Engineers' Club on the evening of November 18. The attendance was approximately 200. His subject was "Recent Advances in Metallurgy from the Standpoint of Crystal Structure".

Mr. Bain briefly described the methods used for X-ray analysis of crystalline metal aggregates and then showed how the crystal structure correlated with the properties of the metal or alloy. He then discussed the allotropic changes in crystal structure at certain temperatures, characteristic of iron and a few other metals. Due to this allotropic change, steel responds to heat treatment owing to the fact that carbon dissolves in face centered cubic iron (gamma iron), and is practically insoluble in body centered iron (alpha iron). He showed the effect of alloying constituents upon these allotropic changes and pointed out their effect upon heat treatment.

The hardening of alloys by the precipitation of compounds therein, was then discussed. This phenomenon is responsible for the hardening of duralumin, the Sykes iron-molybdenum alloys and certain high strength, high copper alloys.

The high chromium stainless steels were also described and the corrosion resistance was attributed to the formation of a permanent oxygen film upon the surface of the alloy.

The changes due to the tempering of various alloy and high speed steels was briefly analyzed and was shown to be due to the decomposition of martensite, followed by the destruction of the retained austenite.

Mr. Bain illustrated his lecture with a large number of slides which were based largely upon the results of his own researches.

A lively discussion followed the talk and this showed the keen interest of the audience.

G. A. Richardson of the Bethlehem Steel Corporation will present, on the evening of December 9, a five reel movie describing all the phases of the "Manufacture of Alloy and Tool Steels". This meeting will be held in the Engineers' Club building and should be of direct interest to all heat treaters.

T. H. Nelson, of the Ludlum Steel Company, will be the speaker for the January meeting and will discuss Nitralloy and its applications.

S. P. Rockwell, inventor of the widely-used Rockwell hardness tester,

will address the March meeting and will demonstrate the application of the dilatometer to the heat treatment of steels. *E. M. Wise.*

CLEVELAND CHAPTER (See Page 1035)

GOLDEN GATE CHAPTER

The regular October meeting of Golden Gate Chapter was held at the Engineers Club on the 13th instant, at which the writer officiated as acting secretary in the absence of C. R. Mens.

The meeting was called to order at 8 o'clock by vice-chairman W. J. Crook, acting in place of the regular chairman who had suddenly been called out of town. The committee chairman called on to report, Mr. Alexander, chairman of the publicity committee, said that the pamphlet showing the personnel of the chapter and the winter's program was now in press and practically all necessary material had been obtained.

Mr. Thurston, chairman of the entertainment committee, discussed plans for the regular December Smoker and a motion was proposed, seconded, and passed, to authorize the entertainment committee to make a charge of $2.50 per head on that occasion. The consensus of opinion was that local talent should make it possible to keep to this relatively low figure.

The question was brought up of an inspection trip to Stanford University and the members were assured by Dr. Crook that it could be arranged on fairly short notice, and at almost any convenient time to the chapter.

The chairman then introduced the first speaker of the evening J. S. Fowler, metallurgist of the Pacific Foundry Company, whose subject was "Cast Iron".

Mr. Fowler touched on the history of cast iron, with a comparison of the characteristics of steel in structural and other uses and then described the raw material and manufacture of the product, with a discussion of cupola practice, tapping, etc. The internal constituents were then taken up one by one, particularly the very vital factor of varying silicon content and its effect on the carbon content. He also described the effect of average proportions of phosphorus, manganese, etc., with comparisons in every case to the more familiar proportions in steel.

The next point was the discussion of the recent efforts at alloying cast iron with such elements as nickel for machinability and wearing qualities, and chromium for whitening. The speaker stressed the importance of careful consideration of the various combinations of the five important elements in producing a wide range of products. He then described semi-steel and other special products of the iron foundry. The uses of cast iron in general were discussed with a number of familiar examples. The talk closed with a description of methods of testing, the most usual being the transverse test, chemical analysis and actual results in service.

This paper was received with a great deal of interest and was followed by an illuminating discussion on such points as the acid-resistant qualities of cast iron, the recent developments of pearlitic iron, etc.

The chairman next introduced the second speaker of the evening, Edward

Foess, of the American Rolling Mill Company, whose subject was "Physical Properties of Metal at Elevated Temperatures". This is a most interesting subject and opens a field of great usefulness which has been the subject of research during the last fifteen years. A majority of tests covered the tensile properties with very little effort to do any work on torsion, etc. Five factors are obviously most important. First, the condition of the specimen, that is, cast, rolled or having received heat treatment, etc. Second, the size, a 2-inch gage length has been used on the most of the tests made, although an 8-inch length is sometimes specified. Third, temperature control and measurement, which represents the greatest problem, and a joint committee of the A. S. T. M. and the A. S. M. E. are now working out standardized methods of procedure. Fourth, the speed of testing; at higher temperatures, an increase of speed shows a large increase in the ultimate strength—in some cases up to 40 per cent. Fifth, some sort of dial arrangement to show test results directly is, of course, a necessity.

The heating of the test piece is usually accomplished by a small electric furnace directly surrounding it, insulated with alundum or similar material. The two customary methods of testing are, first—testing to failure at a given temperature, and second, testing with a prolonged load to failure. The temperature range is normally divided into three sections, 70 to 850 degrees Fahr., to cover the normal requirements of carbon steel; second, 850 to 1100 degrees Fahr.; and third, above 1100 degrees Fahr. The speaker then cited a number of results on carbon steel, alloy steels and the higher heat resisting alloys.

There is but little data available at the present time on torsion tests at high temperatures. This same remark applies also to impact tests. A certain amount of work has been done on hardness tests, showing a progressive decrease of hardness up to 2200 degrees Fahr.

Finally, the speaker discussed the varying effects of oxidation and closed with a number of questions from his interested audience.

After an expression of thanks to the speakers for their efforts, the meeting was closed by the acting chairman.

At the dinner there were 31 present, and over 40 at the meeting itself.

D. Hanson Grubb.

HARTFORD CHAPTER

The November meeting of the Hartford Chapter was held November 9, at the Hartford Electric Light Company Assembly Hall. The meeting was known as "Question Night" and members of the chapter had submitted questions they would like answered and discussed a month previous. The questions were printed on the monthly notices and sent to all members and posted on bulletin boards throughout the manufacturing companies of the city.

The evening was very stormy and only about 50 members and guests were present. Those who came were well repaid as among the members present who came prepared to answer the questions and enter in the discussion were our Chairman, R. W. Woodward, S. P. Rockwell, A. H. d'Arcambal and Lester Lanning.

The questions which brought lively discussion were as follows:

1—Best method for figuring steel treating cost.

2—Knowledge a person should have to intelligently listen in at steel treaters meetings.

3—Most suitable cutting oil for machining steel of 300 Brinell hardness.

4—Interchangeability of hardness testing machines.

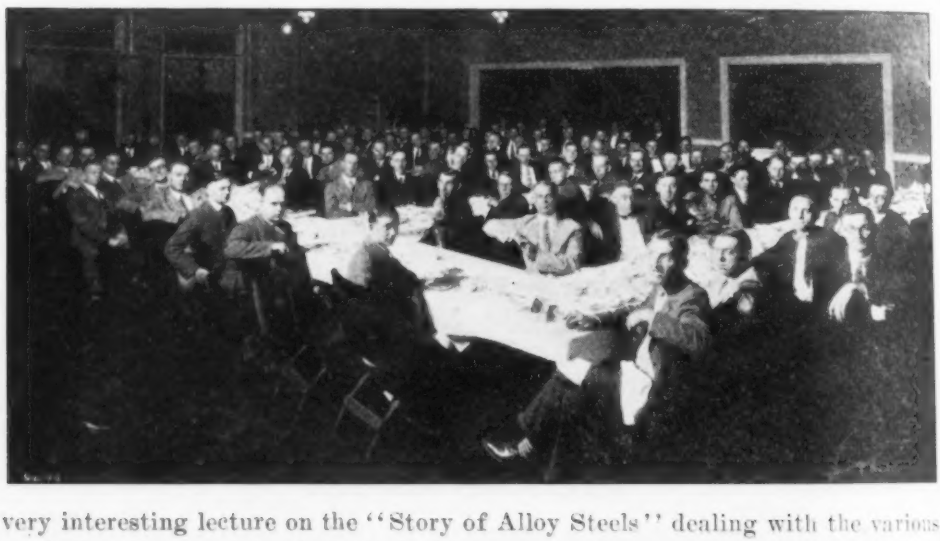
5—The superiority of animal oil over mineral oil in cutting and machining steel.

6—Soft skins developed in hardening cobalt high speed steel.

Questions were asked on the composition, heat treating and annealing brasses and bronzes. This is the first "Question Night" program of the Hartford Chapter to have nonferrous questions appear and make us believe the National Society is looking in the right direction to include nonferrous alloys. *H. J. Fischbeck.*

INDIANAPOLIS CHAPTER

The Indianapolis Chapter held the first Fall meeting on Monday evening, September 13, at the auditorium of the Y. M. C. A. at which time, S. A. Richardson, metallurgist of the Interstate Iron and Steel Company, presented a



very interesting lecture on the "Story of Alloy Steels" dealing with the various methods of manufacturing steels beginning with the ores and tracing the manufacture through to the finished product. With the aid of moving pictures, every man was able to enrich his education in steel making and long discussions followed.

Dinner was served to approximately one hundred members and guests many of whom came from near-by towns and cities. Our mayor gave a short address on city government and cited the necessity of scientific men developing steels for the ever increasing use of that metal. Music was furnished by members of the local chapter. Numerous talks were given regarding the National Steel and Machine Tool Exposition to be held at Chicago during the week of the 20.

The accompanying photograph was taken of the group who assembled for dinner at this meeting. *C. H. Beach.*

On Monday evening, October 8, the members and guests of the local chapter of the Society enjoyed one of the best programs they have had this year and every one present left the meeting with a keen inspiration to really do things in the science of handling steel. Possibly no speaker heretofore has left such a lasting impression. Even though we know a lot about steel and its handling we find that really we do not know many of the fundamentals regarding the science as outlined by the eminent scientist and author, Dr. Guertler, president of the Metallurgical Society of Germany.

While most of those present, mere students, trying to enrich their knowledge of the science of steel, were unable to grasp the deep lines of thought given by the doctor, nevertheless, all benefited from his address on "The Hardness of Metals", which subject undoubtedly had occupied but very little of the time of the average industrial worker. In the discussion which followed the address, Dr. Guertler enlightened the minds of many who had many perplexing questions to ask. The address was supplemented by numerous lantern slides serving to assist the listener in forming a mental picture of all that was said. The inspirations obtained were invaluable.

Promptly at 6:30 those present enjoyed a good dinner and after the usual business meeting which consisted principally of reports on the Chicago Convention held in September, Judge James C. Collins, Judge of the Criminal Court, Marion County, presented a most interesting short talk on "The Young Man Problem" citing his years' experience in handling young men who had slipped from the tracks of righteousness and landed in the courts because of some misdemeanors or offences to society. His talk served to raise the interest of every man present in the "Young Man".

Our regular orchestra was very much in evidence during the serving of the dinner and helped to create the congenialty and good fellowship existing at all our meetings.

Motion for adjournment finally came because of the lateness of the hour and all felt deeply indebted to our speakers.

C. H. Beach.

MONTREAL GROUP

A course of 25 lectures with laboratory demonstrations, and illustrated with lantern slides, apparatus and specimens is being offered by the metallurgical department of McGill University in co-operation with the Montreal Group of the American Society for Steel Treating.

The course will provide an excellent opportunity to learn the fundamental principles of making and treating iron and steel covering their composition, microscopic examination, methods of testing, mechanical and heat treatment, and other related branches of metallurgy.

The course is intended particularly to give instruction in the fundamental principles necessary for a full understanding of the technical lectures and the published proceedings of the American Society for Steel Treating.

The lectures will be given not only by members of the University staff, but also by men prominently engaged in practical steel treating. The lecturing staff will consist of Dr. Stansfield and Messrs. Sproule, Roast, Pascoe and Collitt.

In view of the co-operation between the Metallurgical Department and the Montreal Group of the A. S. S. T. members of the Society can take the course for $5.00. The fee for non-members will be $10.00.

NEW HAVEN CHAPTER

The New Haven Chapter is trying an innovation this year and has planned to hold four sectional meetings outside of New Haven, viz.: two in Bridgeport and two in Waterbury. We have held one in each city so far, and judging from the attendance at both meetings, our new venture is surely proving a success.

Thursday, November 11, was Waterbury Night. At half-past six, twenty-seven members and friends held a get-together dinner at Thorpe's Restaurant.

At eight o'clock we gathered in the Office Building of the Chase Companies, Inc., for the meeting. Last spring when President Bird made a visitation to the New Haven Chapter, we urged the national body to take up the subject of nonferrous metals and we were indeed glad to see this motion passed at the spring sectional meeting in Hartford. As we were one of the first chapters to urge such a step, we wanted to be one of the first chapters to hold such a meeting, so our November meeting was entirely nonferrous and it was most fitting and proper to hold such a meeting in Waterbury because this city is a large producer of nonferrous products.

Our first speaker of the evening was Dr. C. H. Mathewson, chairman of the department of mining and metallurgy, Yale University, whose subject was "New Developments in Zinc." His talk was very well illustrated with lantern slides. He used as a main subject the development of a die cast alloy called "zamak" and from the amount of discussion following his talk, one could readily realize that his subject was very popular.

The second speaker of the evening was D. K. Crampton, metallurgist of the Chase Metal Works whose subject was "Season Cracking of Brass." This talk was also illustrated with slides, and many questions were asked of the speaker following the talk. Never in the history of the New Haven Chapter was discussion entered into as readily as in Waterbury, and we feel justly proud of our first venture into the nonferrous field.

In the absence of our chairman, C. J. Sauer, who was detained in Bridgeport by a heavy cold, our vice-chairman, W. Paul Eddy, Jr., presided, and before the regular speakers talked, introduced F. J. Dawless, chairman of our membership committee, who gave an account of the progress of the membership drive. This drive is going along nicely, but we are not going to be satisfied until we head Group Three with a membership of 100 or more, so get busy and push this drive over by January 1, 1927. We are out to do this, so get busy and do your share.

After an absence of several months, our old friend, H. G. Stigeman, from Bridgeport, was with us again, and he carried off the honors of the evening

by winning the attendance prize which was a twenty-eight piece chest of silverware donated by our chairman, C. J. Sauer. It sometimes pays to be among those present.

It does not seem to matter where the New Haven Chapter holds a meeting, the old guard seems to be always on hand, but we have missed the smiling faces of Major Bellis and E. C. Richardson lately, so we trust they will be out for our next meeting.

Don't forget the membership drive. Do your part and send in a new application. *W. G. Aurand.*

NORTHWEST CHAPTER

The November meeting of the Northwest Chapter was held at the Manufacturers' Association Club Rooms in Minneapolis on November 18. The principal speaker of the evening was N. L. Deuble, of the Central Alloy Steel Corporation of Massillon, Ohio. His subject was the "Heat Treatment of Steel Parts for Motor Cars."

Mr. Deuble first explained the S. A. E. nomenclature used for the classification of carbon and alloy steels. Then proceeding to the individual parts of a motor car, he explained the type of stresses that these parts were designed to resist and then named the kinds of steel and their heat treatment used by automotive manufacturers to attain the desired properties necessary to resist these stresses. The above parts included the front axle, the right and left hand knuckles, king pins, steering arms and tie rod for the front part of the car. For the engine this includes the crank shaft, connecting rod, cam shaft and bearings, and for the propulsion of the car, the transmission gears, spline shafts, torque rod, differential gears and rear axles. Finally the roller and ball bearings and springs were discussed.

From the inspection side, he pointed out that some type of hardness test should be used. Some parts should be tested by the Brinell machine, some by the Rockwell machine and others by the scleroscope. It is assumed that for a given hardness the requirements as to the proper heat treatment has been fulfilled.

This very enlightening paper was followed by an active discussion and the members and friends in attendance showed an exceptional interest in this paper.

The chairman of the Chapter, Dr. Dowdell, then introduced an innovation to our meeting by having H. A. Anderson of the Johnston Manufacturing Company, present an abstract of the paper "Fundamentals of Oil Casting" by Hellings published in the June, 15, number of "The Foundry." It is the intention of the officers of this chapter to have an abstract of some technical paper presented at each regular meeting. *George C. Priester.*

PITTSBURGH CHAPTER

The members of the Pittsburgh Chapter were afforded an unusual opportunity to inspect the plant of the Mesta Machine Co., at West Homestead, Pa., on November 4 at the invitation of that company and were entertained by orchestra and quartet during a splendid dinner which the company served at six o'clock in its dining hall.

About 125 assembled in the Mesta reception room at three o'clock and, after registering and receiving an especially prepared badge authorizing "Inspection of Works", were led in groups of 10 or 12 by a guide through this large plant.

The machine department was first visited. This department is one of the largest and best equipped in the United States. Although some of the equipment was usual still most of it was unusual and of particular interest, some machines of which were: a 100-inch draw cut shaper recently designed and built by this company which is the largest of its kind in the world; horizontal boring mills up to 20 feet in capacity; lathes up to 36 inches in capacity; a pit lathe capable of swinging castings up to 36 feet in diameter; specially designed gear planers capable of cutting helical and double helical gears up to 30 feet in diameter and 6 feet in face; a new design grinding machine for finishing shafts, roll necks, etc.; roll lathes designed and built by this company which are capable of finishing the largest rolls now in use. A notable feature of this department is a large surface plate to receive heavy portable machine tools such as horizontal boring mills, shapers, drill presses, special boring machines, etc., for multiple operations at one time on large castings.

On the way into the foundry department, the visitors were taken through the pattern shop which is unusually well lighted and ventilated and well equipped.

The foundry is one of the largest in the world and one is impressed by the completeness of the overhead and wall crane equipment.

In the iron foundry are eight air furnaces and a cupola having a combined capacity of 200 tons per day. This foundry is equipped with modern molding equipment such as sand handling machinery, core ovens, drying ovens, concrete pouring pits, etc.

The steel foundry, located in the same building which is of unusual length, has four acid open-hearth furnaces, two of 50 tons and two of 40 tons capacity. Some of the largest steel castings in the world have been poured in this foundry which is equipped with modern type drying ovens, ingot pouring pits and annealing ovens.

The metallurgical department is equipped with two tensile testing machines of 100,000 pounds capacity, transverse testing machines, fatigue testing machine and very fine microscopic equipment.

The chemical laboratories are large and well equipped.

The Mesta Machine Company generates all of the heat, light and power used within the plant in its own power house which also contains the air compressors. This is accomplished with a number of Mesta-built units among which are two Mesta Una Flow engines.

The forge shop was next visited. This shop is especially equipped for the production of heavy forgings, although lighter forgings used in Mesta products are also made here. It contains a 2,000-ton forging press capable of handling ingots up to 58 inches in diameter, an 800-ton press of the same type and a number of steam hammers together with the necessary heating and annealing furnaces.

The erecting floor was then visited where each Mesta product, before it is shipped, is assembled as far as possible, operated and tested to assure its satisfactory operation.

This completed the inspection tour and, after being given a few minutes to rest, the visitors were taken to the dining hall where dinner was served while the orchestra and quartet provided a most pleasing program.

After the cigars were lighted, chairman W. H. Phillips called the meeting to order and voiced the appreciation of the Chapter of the splendid hospitality of the Mesta Machine Company to which President Wahr replied for the company in a short speech of welcome.

Ray T. Bayless, editor of the TRANSACTIONS, who was visiting the Pittsburgh Chapter, was then called upon to make a few remarks. After a number of the new members in the Pittsburgh Chapter were introduced, the business of the evening was taken up and disposed of.

The chairman then introduced Walter H. White, superintendent of the open-hearth department of the Duquesne Steel Foundry Co., Coraopolis, Pa., the speaker of the evening, who read a paper on, "Steel Melting Practice", which was followed by the showing of a number of pictures which depicted many problems which Mr. White encountered in steel casting while he was at the U. S. Ordnance Plant at Charleston, W. Va., during the World War.

Mr. White handled his subject from the practical viewpoint and was unusually well received and appreciated by his audience. In introducing the subject he made a plea for the theoretical metallurgists to acquaint themselves more with the melting operation problems by personal experience. He told how physical testing had established standards in the attainment of which the melters owe much of their progress in making better steel. This brought about a study of the slag relationship to the heat and a decision that the slag must be made right before good steel could be made. By keeping a record of over one thousand acid open-hearth heats where physical tests were required, it showed that the slag analysis, color and condition varied with the high and low physical properties and that the green, low iron and manganese slag, "iron and manganese under 35 per cent", gave superior physical properties consistently over the black metallic high iron and manganese slag.

He said that in charging an acid heat on a hot bottom to put in pig first if the bottom is new or low and you want protection and to put in scrap first if the bottom is safe and high. To finish .25/.30 carbon, the charge should analyze: C: 0.75 per cent; Mn: 1.50 per cent; Si: 0.80 per cent; P and S under 0.05 per cent. When melted down it will be: C: 0.50 per cent; Mn: 0.20 per cent; Si: 0.10 per cent. The manganese and silicon later dropping to about 0.05 per cent. As soon as the heat is all clear, limestone to the amount of ⅓ of 1 per cent of the charge should be added and this regardless of whether the slag is thick or thin; add the stone even though the slag is thin and follow with sufficient sand to give proper slag consistency and volume. By taking a slag test at the same time the steel fracture test is taken and cooling it in water, it will be

noted as the heat begins its refining that the slag will gradually turn from a dark metallic color to a light green. The slag should then contain less than "35 per cent iron and manganese" and less than 3.5 per cent CaO.

Mr. White then took up the subject of pouring temperatures and explained their relationship to dry and green sand molds and size of section of the casting. He said that he believed both ingot and casting heats should be poured as cold as good casting will allow and that if a casting or ingot is poured so hot that too much time is allowed between the molten and solid state after the steel is in the mold, harm will always happen.

At the conclusion of his paper, Mr. White explained the pictures which were then shown and he gave many valuable suggestions to his listeners.

A general discussion followed in which many took part. The subject of "flake" and its elimination by good furnace practice received a great deal of attention.

The meeting then adjourned with a rising vote of thanks to Mr. White for his splendid paper and talk.

Harry A. Neeb, Jr.

ROCKFORD CHAPTER

Friday evening, Oct. 29, Rockford Chapter of the American Society for Steel Treating held its meeting at the Nelson Hotel after the usual 7 o'clock supper. The regular business meeting was concluded, after which the floor was turned over to Mr. Peck, chairman of the program committee, who introduced John Nelson of Barber Coleman Company, as speaker of the evening.

Mr. Nelson's paper on "Steel Classification" was enjoyed by everyone because it was of interest to all users of steel. Mr. Nelson classified the steel according to carbon and alloys and told the general applications of each group. He told the effects produced by the various alloys in the percentage that they are present in commercial steel.

After a lively discussion the meeting adjourned.

R. M. Smith.

ST. LOUIS CHAPTER

The 61st regular monthly meeting of the St. Louis Chapter American Society for Steel Treating was held Friday evening, October 29, 1926 at the American Annex Hotel. After the usual dinner and short formal business meeting, the speaker of the evening, Prof. C. W. Cuno, Washington University, was introduced by chairman C. B. Swander.

Professor Cuno's subject was "New Things in Blast Furnace Operations". His discourse carried him from the time when steel industries in England ridiculed American efforts in the making of pig iron with very little success around Pittsburgh, and that some of the first pig iron was produced in the vicinity of St. Louis, and the old blast furnaces can be seen today in a few hours drive to Iron Mountain; and up to the modern melting practice and of a hotter flame than any hitherto known—namely, of 7000 degrees Fahr., even tungsten wire melting like an icicle in a gas jet; when the flame is played on a plate of chromium steel left molten puddles in its wake. The process is where hydrogen is handled in such a

way that metals do not oxidize since they are surrounded by hydrogen gas at the heating and melting point. Professor Cuno closed his talk with an offer to answer questions, which aroused an interesting discussion.

A rising vote of thanks was extended Professor Cuno and the meeting was adjourned. *C. G. Werscheid.*

SCHENECTADY CHAPTER

The second meeting of the Schenectady Chapter was held in the chemistry lecture room at Union College on Friday, October 16. Dr. Guertler gave an address on "The Light Metal Alloys". This proved to be one of the most interesting and valuable addresses presented before the chapter in a long time. Members of the local section of the American Society of Mechanical Engineers were also invited to this meeting.

The third meeting was held in the laboratory building of the American Locomotive Company on Tuesday, November 16. The chemical and physical laboratories were thrown open for inspection for half an hour before the meeting. Full advantage was taken of this privilege. A musical program furnished by the "Testing Trio", William Sebast, Arthur Mengel and our local secretary, James Taylor, began at 7:45.

R. B. McColl, manager of the Schenectady American Locomotive Company plant, opened the meeting at 8:00 with an address of welcome to the forty-six members and guests present. Mr. Tom Nelson, consulting metallurgist for the Ludlum Steel Company, the speaker of the evening, was scheduled to speak on the new nitrogen hardening alloy steel "Nitralloy", but by request took up first the recent developments in stainless steels. After a discussion the talk on Nitralloy followed. This aroused intense interest, and a second active discussion followed. A number of samples on exhibition served as focusing points for part of the discussion.

A prize of a box of cigars was awarded to the member bringing the greatest number of guests to the meeting. This was won by J. Hicks of the American Locomotive Company. *M. F. Sayre.*

SYRACUSE CHAPTER

Professor Essex of the department of physical chemistry of Syracuse University and lecturer in the new night course in heat treatment and metallography of iron and steel spoke to the Syracuse Chapter of the American Society for Steel Treating at its regular meeting on November 9, at the Chamber of Commerce Building. The talk was on general metallography.

The speaker first discussed the two types of solids, amorphous and crystalline, and explained the conditions under which a substance in the amorphous state (liquid) changes to the crystalline state, the size of grain formed being directly proportional to the nuclei number and inversely proportional to the velocity of growth. He next discussed the effects of cold working on metals; the increase in elastic limit without increase of scratch hardness; distortion along slip planes and not along cleavage planes; the breaking down of the material between grains allowing fragments of adjacent grains to grow together or recrystallize at low temperatures; the material between grains cannot be

amorphous metal because, in the first place, amorphous metal has never been produced, and in the second place, the conditions are the opposite of ideal for the formation of amorphous metal; the material between the grains is probably a eutectic of impurity with the pure metal and it is to be expected that this eutectic would be extremely fine grained and hence tenacious. The speaker concluded his talk with a brief discussion of the formation of metal compounds and solid solutions.

The talk was enjoyed by most of the audience in spite of the Professor's use of such high hat language as "heterogeneous catalysis", and the discussions that followed the talk were quite lively.

The program committee headed by Carl Smith has announced the following speakers for the coming meetings.

December 14, 1926—A. H. d'Arcambal of Pratt & Whitney on "METAL CUTTING TOOLS."

January 11, 1927—E. C. Bain of Union Carbide and Carbon Laboratories on "APPLICATION of X-RAY to METALLOGRAPHY."

February 8, 1927—J. V. Emmons of Cleveland Twist Drill on "ANNEALING."

March 8, 1927—J. P. Gill of Vanadium Alloy Steel Company on "HIGH SPEED STEEL."

April 12, 1927—F. C. Rabb of Brown Lipe Chapin on "CARBURIZING."

May 9, 1927—Jerome Strauss of U. S. Navy Yard on "CORROSION."

S. P. Peskowitz.

TRI-CITY CHAPTER

The October meeting of the Tri-City Chapter of the American Society for Steel Treating was held October 21, at the Davenport Chamber of Commerce. Between thirty-five and forty members and friends enjoyed dinner and several good talks.

G. A. Uhlmeyer, industrial engineer for the Peoples Power Company, gave a talk on modern industrial heat treating equipment. The fuels of the future for this work are undoubtedly gas and electricity. He pointed out the tendency of the modern furnace designer to insulate heavily and to apply continuous type furnaces where production methods will permit. This fact, together with automatic temperature control, conveyors for material, etc., reduces labor costs and the human element of chance in securing quality products. In other words a product of uniform high quality is produced with greater ease than with older types of equipment.

A. C. Schoessel, general superintendent of the Deere Harvester Plant, East Moline, gave a talk covering his visits through the Pullman Works and the American Forge Company, both of Chicago. He pointed out that although some of the plants are very old, they still maintain their place in the industrial world by the use of modern equipment.

The talk of the evening was given by Robert K. Barry of the Barry Manufacturing Company of Muscatine, Iowa. The product turned out by this plant consists of various complicated cutters, drills, hobbs, etc. Considerable of this equipment is being used at the button factories of Mus-

catine, for cutting, shaping and polishing buttons. Mr. Barry's talk covered his own and his associates' experiences with various methods of conducting heat treating operations. He pointed out that a two-compartment preheating type gas furnace has given him the best results for heating high speed steels. He favors a salt bath for quenching with subsequent drawing in oil.

Heat treating of steel is going through a transition at the present time. In times past this work was more or less of an art. The quality of the product depending entirely upon the skill of the operator. From an art, heat treating is fast becoming one of the exact sciences. The kind of treatment being governed by the chemical composition of the steel. Furnaces are becoming heating machines which regulate rate of heating, time of heat, temperature, automatically charged and discharged, eliminating largely the human element. *G. A. Uhlmeyer.*

WASHINGTON-BALTIMORE CHAPTER

The opening meeting for the 1926-1927 season (a joint meeting with the Washington Society of Engineers) was held in the Cosmos Club Assembly Hall on October 29.

Dr. William M. Guertler, Director of the Metall Institut of the Charlottenburg Polytechnik, Berlin, Germany, favored the meeting with a most interesting and instructive talk on the subject of "The Light Metal Alloys."

More than twenty members of the two societies assembled for dinner at the Club prior to the meeting, and following dinner Dr. Guertler gave a short talk on his impression of American research. The first part of the speaker's treatment of the light metals was devoted to the magnesium alloys. He remarked that until quite recently a great amount of magnesium chloride had been cast aside as waste, but a realization of its potential value caused Germany to develop methods for producing magnesium from it. Later magnesium alloys were brought forth, the so-called "Electron" alloys being among the most important. He also pointed out that magnesium alloys had recently been developed which showed age-hardening characteristics similar to duralumin. At the present time many parts of German automobiles, aircraft and even experimentally the wheels of heavy trucks are made of magnesium alloys. But these metals do not stand salt water attack. They must be protected from contact with corroding media as is the case with many iron alloys. According to Dr. Guertler, magnesium alloys have a great future and will at some later time be strong competitors of the aluminum alloys.

These aluminum alloys were treated by the speaker from such a broad point of view and such an abundance of data was presented that no attempt is here made to present a detailed report. Dr. Guertler emphasized the high electrical conductivity of aluminum and its alloys and mentioned that a committee of German experts found that aluminum conductors stand up very well under service conditions. The maximum electrical conductivity of cold-worked commercial aluminum (99%) is obtained when it is annealed at 240 degrees Cent.; this phenomenon was found to be associated with the silicon content normally present. Considerable conductivity data on commercial aluminum-base alloys

were presented and strength-conductivity relationships considered. Aluminum and its alloys were said to be employed extensively in Germany for electrical equipment. Photographs were shown of a large electro-magnet for handling scrap iron and of a portable electric drill which were made almost entirely of aluminum alloys, even including the windings.

Aluminum resists fairly well corrosion by water, nitric acid and numerous other solutions. Attention was called to the fact that there has been established in Germany a Central Bureau for research and dissemination of information regarding aluminum and its alloys. Service results secured in the use of these alloys in the chemical industries have been published and have resulted in extended applications.

A number of diagrams, charts and micrographs of various aluminum alloys were next explained. The importance of the intermetallic compounds and the results to be secured when considering them as components of binary or more complex systems, was pointed out. An Al-Zn-Mg super-duralumin alloy having a tensile strength of 90,000 pounds per square inch with 5 per cent elongation, when cold-worked, was mentioned. This alloy is the result of painstaking study of the equilibrium conditions in a great number of systems of which compounds are components.

At the end of the talk a beautiful collection of single crystals was exhibited.

In the course of the discussion many interesting subjects were dealt with. It was explained that:

1. The so-called super-duralumin (Al-Mg-Zn) alloy is valuable only when in the wrought condition. It is not a good casting alloy.
2. There are now several duralumin-like alloys developed in Germany, among which is an aluminum-zinc-lithium alloy.
3. Some of the oxide coatings formed on aluminum alloys by chemical attack work fairly satisfactorily.
4. The mechanism of "modification" of Al-Si alloys (such as in the "Alpax" process) may be explained by undercooling. Some elements, for example sodium, effect this undercooling and consequently prevent coarse grain formation.
5. Welding of aluminum alloys is often unsatisfactory, as cold work and age-hardening effects are destroyed during this operation and the metal therefore must be cold-worked or hardened again; even then the weld is much inferior to the adjacent metal. A process of hammer welding of aluminum sheets involving novel processing methods, has met with considerable commercial success.
6. Purification of magnesium (made by electrolysis of the chloride) is developed to such an extent that there are no traces of chlorine in the product.
7. Metallic beryllium has been experimented with to some degree; although brittle when containing impurities, it is ductile in the pure state.

In regard to the question of whether corrosion of duralumin may be re-

duced by special heat treatment, the speaker remarked that, although such a condition was not known to him, he believed that methods of quenching should have some bearing on corrosion.

At the close of the meeting an enthusiastic rising vote of thanks was accorded to Dr. Guertler. *A. I. Krynitsky.*

CLEVELAND CHAPTER

On Friday, November 19, 1926, the Cleveland Chapter had a very interesting and practical address entitled "Steel Selection for Automotive Work as Applied in the Ford Plants."

The subject was presented by Mr. J. L. McCloud of the Central Metallurgical Laboratory, Ford Motor Company, Dearborn, Michigan.

Mr. McCloud showed an unusual amount of experience in his subject, and especially on the practical side of the subject. He handled the subject from an engineering, metallurgical and practical point of view so that he could be followed with great interest by all.

The speaker discussed all of the steels used in the Ford Company, stating their numbers, analyses and uses, showing that for certain parts material is held to within 5 points of carbon. All material is inspected thoroughly and sorted.

The heat treatment of their steels was thoroughly explained, and many became interested in some of their special treatments.

The speaker covered this unusually large subject on his experiences and applications of material to light automobiles, heavy expensive cars, tractors, railroad stock and air craft in an excellent manner.

After the address Mr. McCloud answered a number of questions.

This meeting was held on the fourth floor of Carnegie Hall, 1220 Huron Road.

About one hundred members and guests were in attendance, about twenty-five being present at the dinner at 6:30 p. m. at Bohanon & Haines restaurant on the second floor of the same building.

A. E. Buelow.

DISCUSSION—THE IRON-MOLYBDENUM SYSTEM

(Continued from Page 871)

lagging effect in the unit parameter is due to the hysteresis effect in pure metal or to a separation of some constituent from the space lattice as it existed at those other temperatures.

I would like to know if Mr. Sykes has considered those problems?

W. P. SYKES: Just to answer that last question. These alloys have not been subjected to the X-ray inspection during any stage of aging as yet. We hope to get to it eventually. So I cannot tell whether there is any change in the parameter or not accompanying that aging and shrinkage. The only thing we can be sure of or feel fairly sure of is that along with the shrinkage the formation and precipitation of the compound occurs, of course changing the space lattice to some extent.

Items of Interest

THE university and the steel mills of the city of Syracuse have arranged a course in the metallurgy of iron and steel. This correlates theory and practice and makes possible cooperative education. It is a great advance for both industry and education. Teachers and lecturers from the university and from industry will comprise the teaching staff.

The course will consist of four hours of laboratory work and a one-hour lecture per week for a period of 32 weeks. Especial attention will be given to the properties and composition of iron and steel, their methods of manufacture and testing.

R. J. Giblin, metallurgical engineer, Buick Motor Company, Flint, Michigan, died November 17. He was a member of Detroit Chapter of this Society and one of the members of the Sub-Committee on the Carburizing of Small Parts.

F. B. Foley has recently been made superintendent of the research department of the Midvale Company, Nicetown, Philadelphia. He was formerly metallurgist of Lucey Manufacturing Corporation, Chattanooga, Tenn. During the war he studied and wrote on the "flake" phenomenon in gun steel. After the war he served in the capacity of metallurgist for the Bureau of Mines and still continues as a consulting metallurgist. He also worked with the late Henry Marion Howe in conducting investigations of the effect of variations in heating and cooling on the physical properties of carbon steel. He also made wide survey of the treatment and handling of drill steel. He is a member of many organizations whose chief purpose it is to further research along metallurgical lines.

On November 17, the city of Newark fittingly observed the 138th anniversary of the birth of Seth Boyden, the discoverer of malleable iron and a man of great inventive genius. His outstanding achievements are enumerated on a bronze tablet attached to the Boyden monument in Washington Park, Newark. This was unveiled by Norman Crawford, a great-great-grandson of Seth Boyden. Thus does posterity do honor to the men who have made our present-day civilization possible.

Announcement was made Nov. 9 that the Timken Roller Bearing Company has obtained the order for the bearings for 127 railroad cars for the Chicago, Milwaukee and St. Paul Railroad. These cars will all be used on the two crack trains of the railroad, one the Pioneer Limited, running between Chicago and Minneapolis, and the other, the Olympian, running from Chicago to Tacoma and Seattle. The equipment for the Olympian will consist of 9 trains, one each day, each way. The equipment for the Pioneer Limited will consist of three trains.

(Continued on Page 34 Adv. Sec.)

Employment Service Bureau

This bureau is for all members of the Society. Want ads will be printed at the following rates: minimum of 30 words $0.50; each additional word $0.02.

This service is also for employers, whether members of the Society or not. Rates for this service are as follows: minimum of 50 words $1.00; each additional word $0.02. Fee must accompany copy.

Address answers care of AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave., Cleveland, unless otherwise stated.

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METALLURGIST AND CHEMIST desires change offering future in exchange for 15 years of unusual practical experience in the heat treatment of all types of steel and non-ferrous metals. Familiar with the manufacture of die castings and electro plating processes. Will consider connection in executive or technical sales capacity. Married. Inquiries solicited. Address 11-10.

TECHNICAL GRADUATE, S. M., in Mechanical Engineering from the Massachusetts Institute of Technology, Cambridge, with advanced training in the testing, heat treatment and metallography of iron and steel, desires position in a plant or laboratory. Address 12-15.

Are you using the right kind of steel for your work and are you getting the results you expect from its heat treating? If not, consult one who has a successful record in straightening out steel troubles. Address 12-20.

METALLURGIST wants opening in either steel mill laboratory or automobile plant research—or claim department. Graduate from German college. One year's experience, very best references. Address 12-25.

Tool hardener with ten years' experience in hardening of dies, reamers, broaches, punches, jigs, and the heat treating of alloy steels would like position with concern in Cleveland, Detroit or Pittsburgh. Address 12-30.

POSITIONS OPEN

DISTRICT SALES MANAGER wanted; to be located in Philadelphia, to take care of that general district. Must be college graduate in metallurgy and have sales experience with tool steel concern. Age, approximately 30-35. Good salary assured to experienced tool steel executive salesman. Communicate direct with Braeburn Alloy Steel Corporation, Braeburn, Pa.

SALES MANAGER—For Tool Steel Company, manufacturing high speed, alloy and carbon tool steel. State age and experience. Address 12-5.

WANTED—Tool steel salesman for New England territory. Salary and commission. Fine opportunity for young man having metallurgical training and some tool steel sales experience. Address 12-10.

WANTED—Young men to become service experts and maintenance men for high grade mechanical and electrical equipment as used in large industrial plants and factories in electrically controlling and recording temperature and pressure. Excellent opportunities for promotion after thorough course of training in factory of large manufacturer of instruments and controllers. In applying describe mechanical ability, previous experience if any and education. Young single men preferred who are free for quick transfers. Address 12-40.

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[1]There are 12 lines to an inch. A charge of 40 cents per line will be made for extra lines.

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1 Stewart, No. 10, Oven Furnace for Heat Treating, Annealing, and Carbonizing, used but a short time, in excellent condition. Price very reasonable. KOHLER DIE & SPECIALTY CO., DeKalb, Ill.

The Chrome Alloy Tube Corporation announce the following changes in their organization. At the last meeting of the Board of Directors the following officers were elected: President, J. T. Pratt; vice-president, E. W. Bachman; vice-president, A. V. Farr; secretary-treasurer, L. C. Owens, Jr.

Mr. Bachman will continue his duties in charge of production at the plant at Newark, N. J.

Mr. Farr recently resigned as sales manager of the Roland Steel Company to take charge of sales of the Chrome Alloy Tube Corporation.

The company also announces that headquarters have been moved to 26 Broadway, New York City, from Newark, N. J., where they manufacture welded tubing of Enduro, Ascoloy, Delhi, Uniloy and other stainless irons. They have successfully welded various alloys in tube form which hitherto have not been successfully produced on a commercial basis.

The Braeburn Alloy Steel Corporation announces the election of T. H. McGraw Jr. as president, at their last meeting of the directors. Mr. McGraw has served as chairman of the board since the first of May 1926.

The product of this company is tool steel, including cobalt, tungsten, vanadium and straight carbon products. Mr. McGraw has served as secretary and director of the Standard Seamless Tube Company, at Ambridge, Pa., for the past twelve years; he was general manager of the Carbon Steel Company for two years.

Worcester Chapter finds that the money which was appropriated to support the metallurgical course given at the Y. M. C. A. will not need to be used as the attendance is considerably more than was expected and the course is paying for itself.

"An Illustrated Story" is the title of a pamphlet setting forth the origin, progress, reward, and products of the William Ganschow Company, 1017 West Washington Blvd. This was the first gear company in Chicago. the gear center of the world. Sent on request.

The Stanley P. Rockwell, 66 Trumbull Street, Hartford, Conn., has available Bulletin No. 2611 which pertains to the Rockwell Dilatometer and Volcrit method of heat-treatment. This shows the comparison of methods of precision heat-treatment, and sets forth how the proper quenching point is indicated automatically and without lag of indication.

That American industry is more and more turning to applied science to aid in solving its many and intricate technical problems is indicated in the annual report of George K. Burgess, Director of the Bureau of Standards, of Department of Commerce, made public November 23, 1926.

The Bureau of Standards, the report shows, maintains contact with industry through approximately 80 advisory committees and through a large number of "research associates" who are sent by industrial groups to work on problems of interest to their respective industries. Results are quickly applied by the industries concerned so that the public soon benefits from im-

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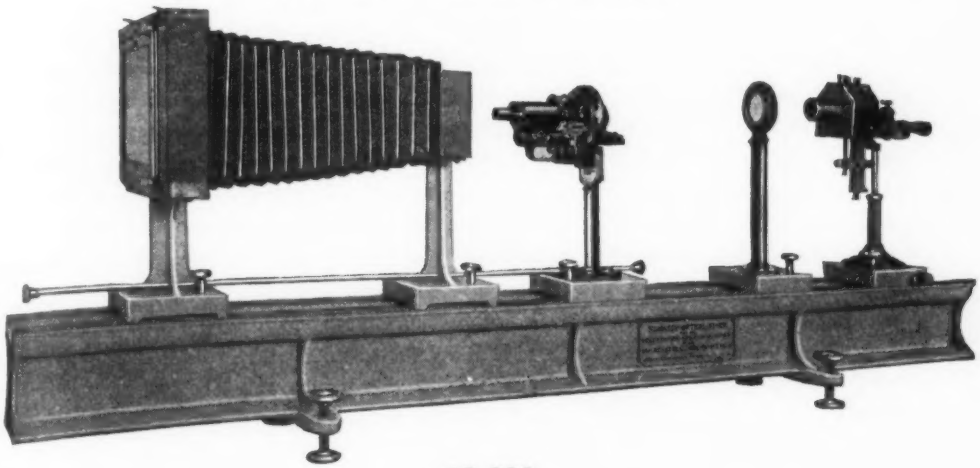

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The equipment includes a condensing lens on a separate support, a hand-fed arc lamp with horizontal and vertical adjustment, and a special camera for plates 6½x8½ inches, 5x7 inches, and 4x5 inches.

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proved processes. During the fiscal year 1925-26 there were 62 of those associates at the bureau, representing 36 separate industries.

Nearly 180,000 tests having a fee value of $675,046, the report points out, were completed by the bureau during the year. The character and scope of these tests spanned the province of applied science from sugar to cement, from thermometers and pyrometers to paints and varnishes, and from aerial photography to studies in city planning. In addition to a vast amount of consulting and specification work for various Government departments, specific research work covering 40 projects was performed for 15 Government establishments.

The work in the field of simplified practice was actively carried on, the report shows forty-five simplified practice recommendations have been accepted by industries, resulting in great savings in the production of articles in common use. This is one of the most important ways it is pointed out in which an industry can effect immediate economies, and the demand for publications on this work is evidence of the interest manufacturers are showing in it.

The work on building and housing produced some important results. A standard building code, submitted for general adoption, was drawn up by a special committee. A report was issued on the important subject of city planning and zoning, containing a list of 436 municipalities which have adopted zoning ordinances.

Among the outstanding research undertakings of the bureau during the year was that in connection with increasing the wearing quality of our paper currency. By introducing certain changes in the manufacturing process, a paper was developed which it is believed will increase the life of bills by fully fifty per cent.

A blue glass was developed for protecting the eyes of furnace workers which gives a good contrast between the appearance of the furnace walls and the melt and yet cuts out the dangerous ultraviolet radiation. The camera used in making maps from airplanes was improved by introducing a plate of glass between the lens and film which eliminates distortion of the picture and reduces by one half of the flying time required for this work.

In the radio field, the report shows, the bureau has continued its studies of ways for reducing interference between broadcasting stations. The piezo oscillator, which employs a quartz plate possessing a definite mechanical frequency of vibration, has been developed as a practical and successful device for holding transmitting stations exactly on their assigned wave lengths. Standard frequency signals have been transmitted from the bureau's station and the station at Stanford University, California, which have proved very useful in standardizing radio apparatus all over the country. A special direction finder was developed and installed on Coast Guard patrol boats, which could easily be added to the existing radio equipment.

Many important investigations were made at the bureau of the strength of building materials, including a program of 30 tests on brick walls in the 10-million pound compression testing machine, and other tests on steel columns. Fire tests were made on many types of walls, of theater curtains and of sheet metal garages.

In concluding his report, Dr. Burgess points out the important needs of the bureau during the current year. These include adequate support for the test work, and an appropriation for a new power plant, authority for the construction of which was granted at the last session of Congress.

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LOCKPORT, NEW YORK

J. H. G. Monypenny, Sheffield, England, in his book entitled "Stainless Iron and Steel" gives an interesting and comprehensive history of the development of these products.

Stainless steel became known to the world in 1914 and was first used for the manufacture of table cutlery. It now has many and varied applications in the engineering field. Beginning with perhaps but one distinct set of known properties it now has developed into a series of steels capable of being used for all sorts of purposes. The author sets forth the valuable contributions made by Harry Brearley in the field of stainless iron and steel. Much of the special stainless steel made now is manufactured according to the specifications made by the inventor in 1915. Most of the development along the production of stainless iron and steel since that time have been along the lines of standardizing types of the steel especially as regards carbon content. The writer is of the opinion that the composition of stainless steel should be entirely determined by the ultimate use to which it is to be put. The distinguishing property of resistance to corrosion is primarily brought about by the addition of chromium to ordinary steel and the author devotes an entire chapter of his book to the influence of chromium on the structure and hardness of steel. He feels that the development of the science of metallography has aided quite materially in the development of steels.

Special attention is given to the composition, making, working and treatment of stainless steel; to its mechanical and physical properties; resistance to corrosion; the effects of various acids; atmosphere; river, sea, well, tap and sea water; chemicals such as chlorides and sulphates, etc.

Stainless steel seems in Mr. Monypenny's opinion to be a highly specialized commodity and in his consideration of special stainless steels he gives this much stress and says that while raising the chromium content to say 16 or even 20 per cent makes steel resistive to severely corrosive conditions, yet, unless high in carbon content, they have no capacity for hardening. Hence the necessity for considering the non-corrosive requirements and the best combination of physical properties. For cutlery it must be capable of carrying a sharp edge as well as resistant to corrosion and yet it must be to a certain extent pliable—"springy." In surgical instruments it must be capable of being sterilized with various disinfectants. In valves for aeroplane engines and internal combustion engines high temperatures must be given consideration and play an important role in the determination of the composition of the stainless steel from which they are made.

The author says that the year 1925 was a notable one in the engineering world and it was the centenary of the railway and he devotes considerable space to the opportunities afforded for testing the properties of stainless steel in the modern locomotive.

In the closing chapter of the book entitled "Some Applications of Stainless Steel" the author indicates that since 1919 considerable progress has been made in the manufacture of stainless steel and how it is benefiting human progress.

The appendix contains the texts of the Canadian and United States patents for the manufacture of stainless steel.

The subject matter is illustrated by the incorporation of photomicrographs and tables and graphs add to its concreteness.

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Transactions of American Society for Steel Treating

Vol. X December, 1926 No. 6

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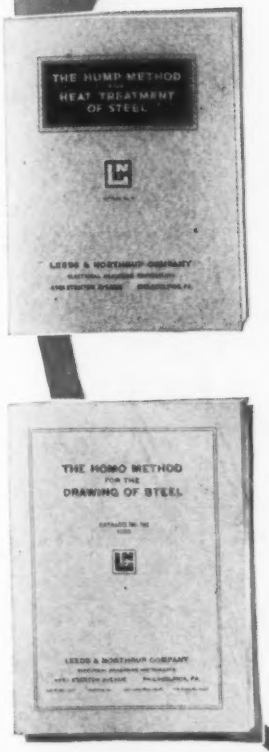

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RAY T. BAYLESS, *Editor*

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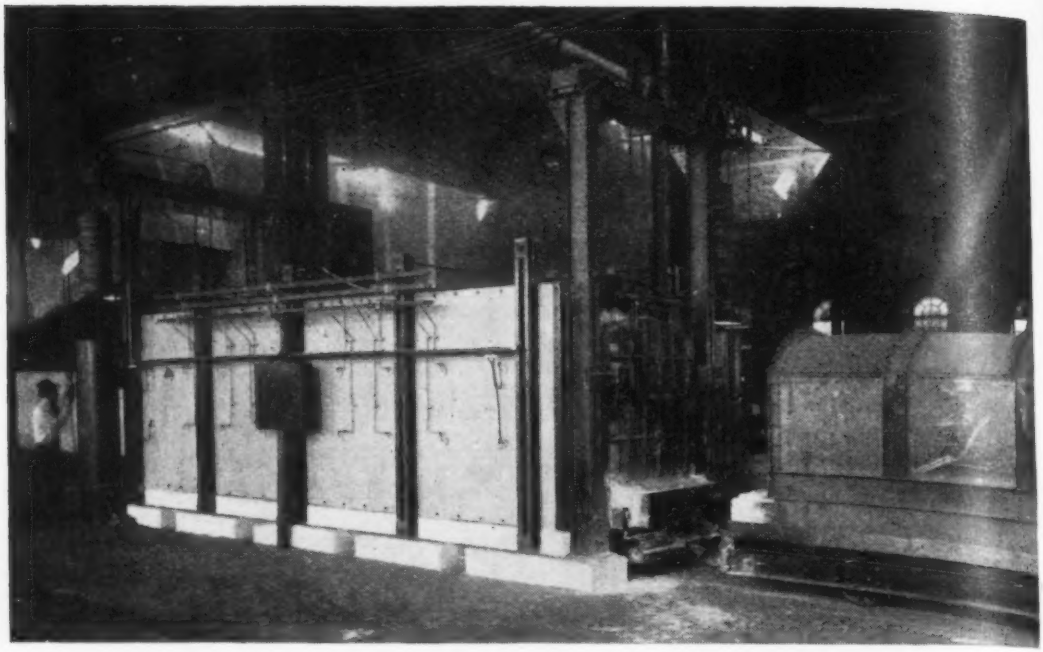

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HEART TO HEART TALK WITH STEEL TREATERS

By the President of

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OUR VIM Leather Department has been complaining because the are charged with a portion of the cost of this space and we rarel mention VIM Leather, or VIM Leather Products, in these Talk Gilbert & Sullivan immortalized the saying, "A policeman's life is n a happy one," but a policeman has a cinch compared with an advertisin manager who tries to equitably apportion his advertising efforts amon several departments.

VIM Leather is the toughest and most durable, flexible fabr made. This is because it is made from the heaviest and toughest hid procurable in quantities, by a process that will preserve 100% of th original fibers of the hide, plus the fact that the finished leather is a no oxidizable material.

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uty was to supply Mr. Foerderer with information as to what was equired of the leather.

Members of the Society will, therefore, appreciate that we are lways most willing to give credit where credit is due.

Let me give you a common sense illustration of just what VIM eather will do.

On my 60 foot yeacht, it is usual to carry fenders, to protect the acht from docks, but more particularly to protect it from boats coming ongside. We carry a 24 foot bank or fishing skiff and it is made fast o the port side most of the time. The ordinary fenders are composed f the heaviest canvas, filled with cork. Two fenders are kept over the de most of the time, and usually last 30 days before showing signs of ear, meaning before bursting and spilling the granulated cork con- nts. In addition to the pressure the fenders are subjected to the xidizing effect of salt water.

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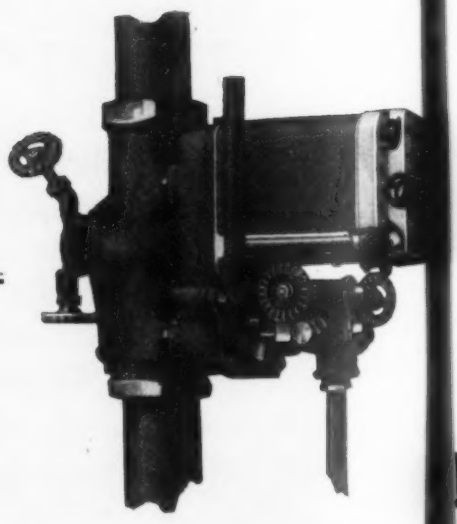

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Alloy Steels Speed the World's Progress

THE farmer's automobile takes him to market—and back—in the time it used to take Old Dobbin to get to the first watering-trough. The city dweller depends upon trolley, tube or "L" to get him to his day's work. Goods are moved by train or truck more quickly and surely than ever before.

Because flawless mechanisms turn and spin on tracks or highways—delivering power when and as wanted—travelers arrive on time and as promptly depart. Alloy Steels have made dependable transportation a reality. For stress members and moving parts of vehicles of every kind, engineers have recommended various types of Alloy Steel. To meet the need for a material that is strong but light, tough but elastic, adaptable to the many different requirements, these metallurgists have chosen Alloy Steel.

With from 25% to 100% greater loading capacity than carbon steels, and with more hardness and strength per unit of cross-section, Alloy Steels have a shock resistance that is remarkable. They endure where other metals fail.

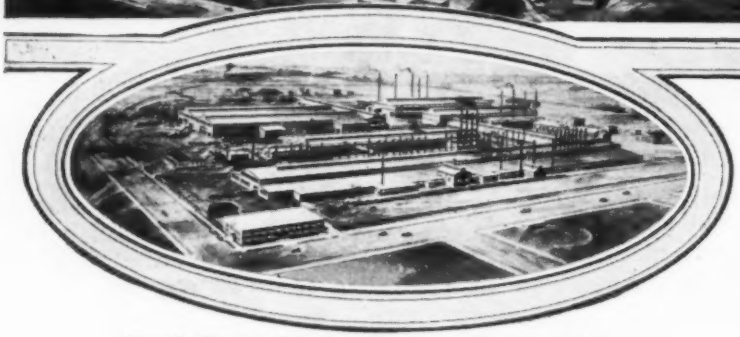
Alloy Steels are necessary to the engineering plans of industry, everywhere. They will fit into YOUR plans. Why not let our engineers tell you how and where Alloy Steel can help in the solution of your metal problems? Our laboratory facilities are at your disposal.

In the famous Mack trucks made by The International Motor Company of New York, Nickel-bearing Steels have been used for such vital parts as: frames; axles; steering knuckles, arms, pins, worms, and gears; spring clips; cam shafts, and rollers; transmission, differential, and double reduction gears; jack shafts, and rear axle driveshafts.

This folder for permanently filing Nickel Steel data will be sent free on request. Write for it today, mentioning this periodical.

ALLOY STEEL

THE INTERNATIONAL NICKEL COMPANY, 67 WALL STREET, NEW YORK CITY.
Producers of INCO Nickel in all commercial forms



Main Plant of United Division, Canton, Ohio

South Plant of United Division, Canton, Ohio

Now—

Two Sources of Supply fro

Agathon Alloy Steels In Daily Production

Nickel, Chrome-Nickel
UMA, Molybdenum
Chrome-Molybdenum
Nickel-Molybdenum
Vanadium, Chrome-Vanadium, Chromium, etc.
Deliveries in Blooms, Billets, Slabs, Hot Rolled, Heat Treated, and Cold Drawn Bars.

THE CENTRAL ALLOY STEEL CORPORATION combines two distinct and completely self-contained steel plants with facilities so complete as to constitute virtually two sources of supply.

No other organization is so thoroughly equipped with metallurgical ability for scientific research and for the actual supervision of high quality production.

The Central Division, at Massillon, Ohio, has a blast furnace of 800 tons daily capacity, which will be served by a 49-oven by-product coke plant. Melting and rolling capacity for a yearly production of 400,000 tons of alloy steel blooms, billets, bars, etc., 100,000 tons of hot-rolled strip for automobile frames, brake drums and all heavy stampings, and 70,000 tons of special finish sheets make this one of the most

AGATHON STEELS

AGATHON

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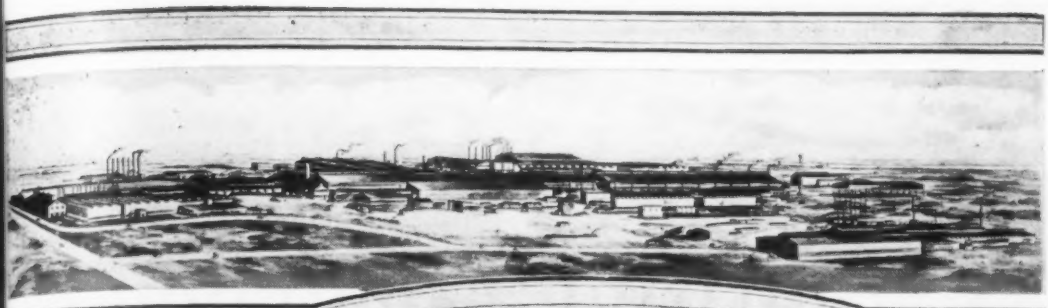

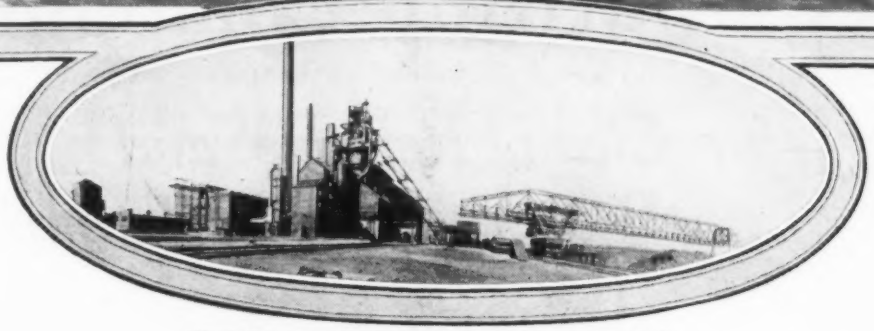

Main Plant of Central Division, Massillon, Ohio

Blast Furnace, Central Division, Massillon, Ohio

from Ore to Finished Steel

important units in the special steel industry.

The United Division, at Canton, Ohio, has a blast furnace of 650 tons daily capacity, served by a 47-oven by-product coke plant. The capacity for alloy, carbon and special steel blooms, billets, bars, etc., is 520,000 tons per year. Electric furnace equipment provides 50,000 tons of electric steels annually, while the capacity in both common and special finish sheets, black, galvanized, terne-coated, etc., is 280,000 tons per year.

The combined facilities of this great organization make possible to a greater degree than ever before a highly efficient and well-rounded service to the user of alloy steels and sheets.

Central Alloy Steel Corporation

Massillon, Ohio

CLEVELAND DETROIT CHICAGO NEW YORK
SYRUCUSE PHILADELPHIA LOS ANGELES TULSA

Other Agathon Products

High Finish Sheets
Blue Annealed Sheets
Black Sheets
Galvanized Sheets
Terne-coated Sheets
Hot Rolled Strips
Toncan Metal
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Carburizing Compounds
—*for Clean, Reliable and Economical Carburizing*

Char Carburizing Compounds
are characterized by

Low Shrinkage:
—because they are pre-shrunk in processing.

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—because each particle has a protective coating of dense, pure carbon.

Constant Activity:
—with small amounts of new added—because the protective coating prevents loss of energizer.

CHAR Carburizing Compounds are designed for a clean, reliable and economical carburizing practice.

And the experiences of a constantly growing number of well-known users substantiate our claim for superior performance in each of these respects.

May we send you particulars —and samples?

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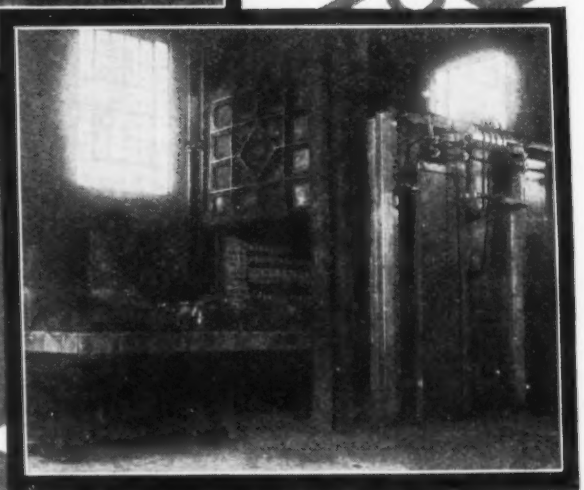
Volume Production and Controlled Costs Demand The Best in Furnace Construction and Design.

THE definite economies and increased production possible with Hagan Equipment is the reason for the unequaled popularity of Hagan Furnaces. ¶ We will be glad to consult with you.

GEORGE J. HAGAN COMPANY

Chamber of Commerce Bldg. Pittsburgh, Penna.

A Standard Hagan C72 Heat Treating Furnace Built for the Keystone Driller Co., Beaver Falls, Penna.



Car Type Annealing Furnace Built for the Otis Elevator Company, Buffalo, N. Y.

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Timken Steel

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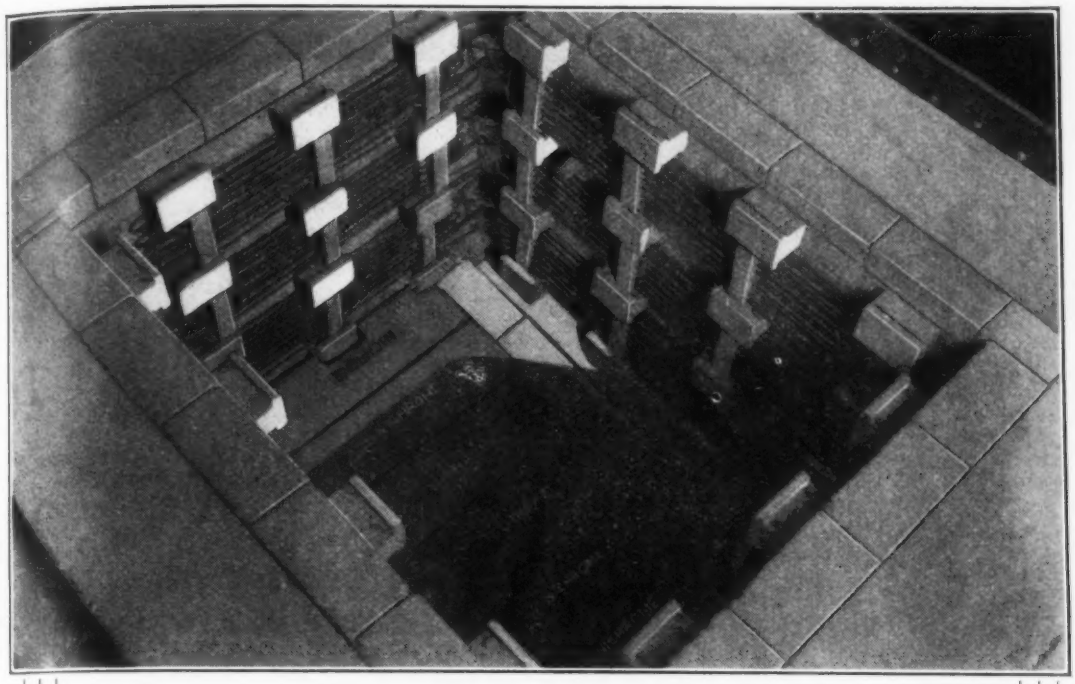

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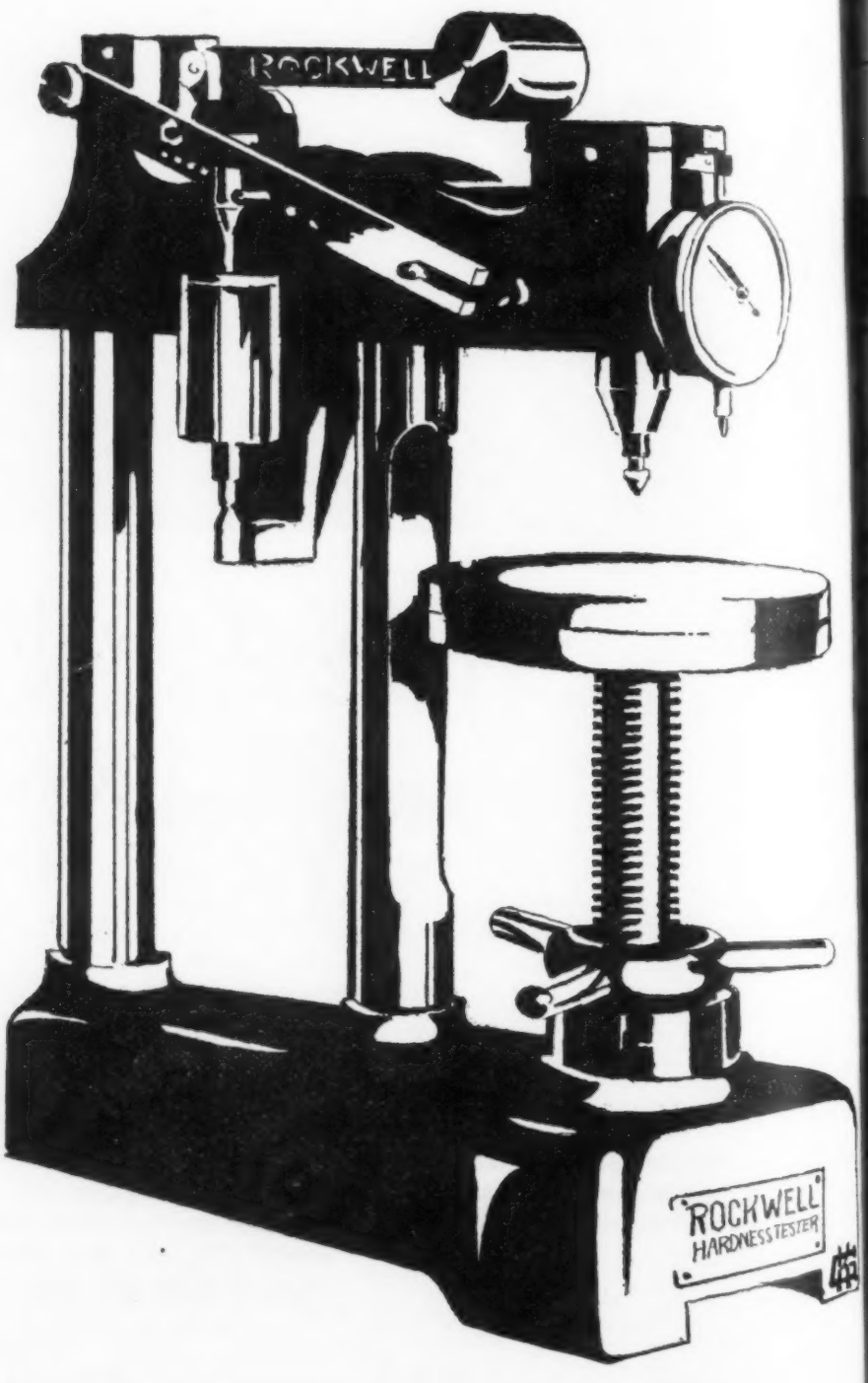

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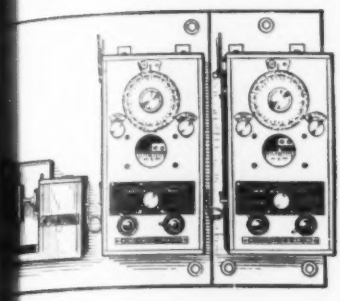
AT TREATMENT OF STEEL

PYROMETERS



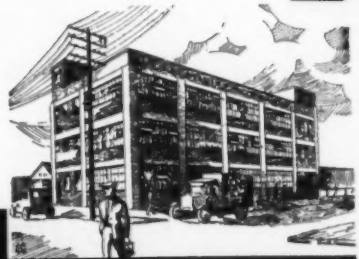
The PROBLEM
of Automatic Control
of Temperature

E application of Automatic Temperature Control in Industrial Heating is not alone a matter of automatically ng and closing switches or fuel valves in response to erature changes, for many other factors are involved.

Automatic temperature control should not be interpreted y as automatic control of good furnace output, for in cases furnace atmosphere, the time element on heating, fuel uniformity and constancy enter largely into the r.

With various factors that must be solved as individual ems on each application of automatic control, it becomes ularly important to employ pyrometric control equip- that is positive and dependable, sensitive and accurate, t no complications be added.

The Wilson-Maeulen Controller will hold down its end t your attention may concentrate upon the factors that n to the special features of your own par- heating job.



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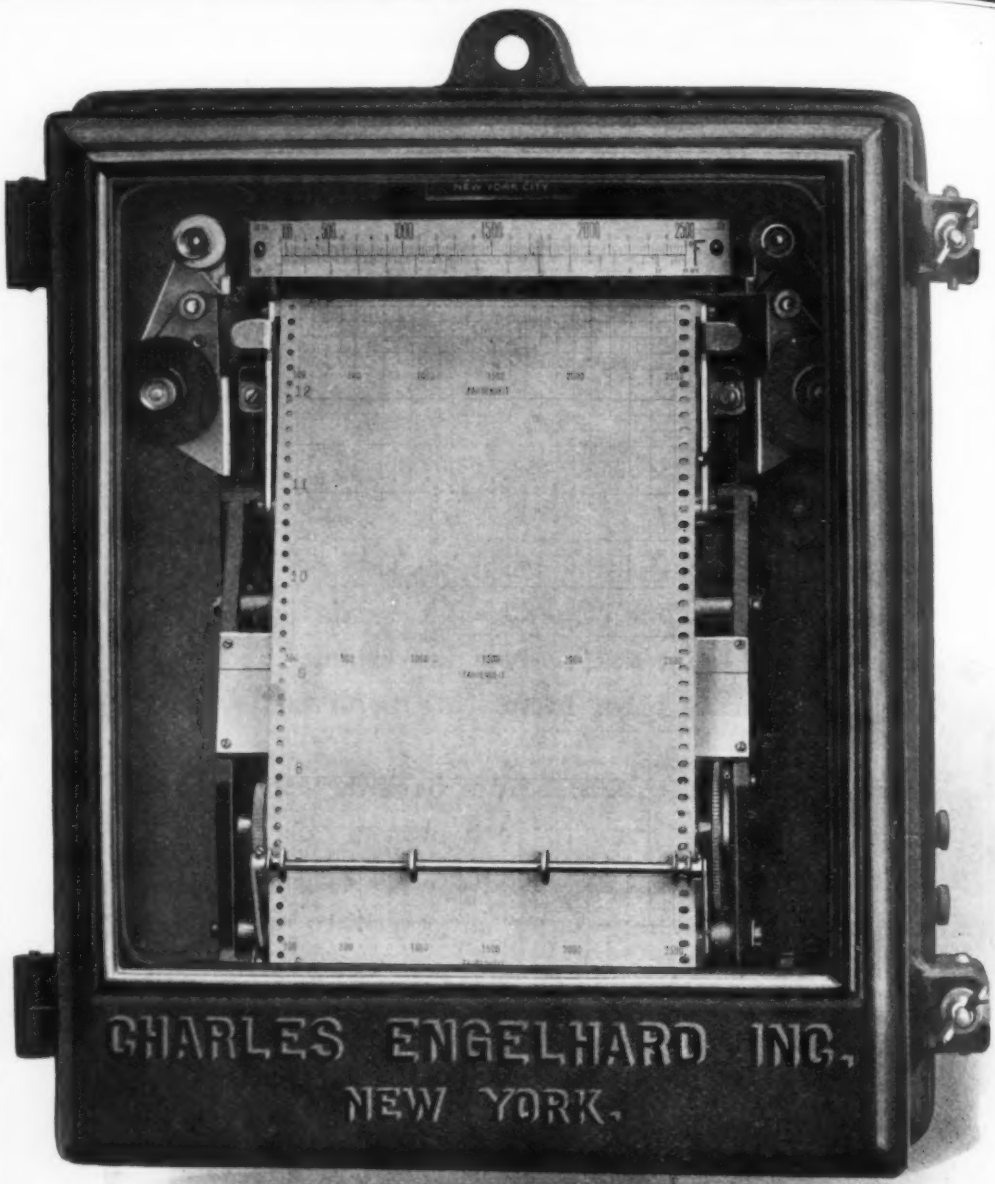

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NON-DEFORMING OIL HARDENING

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DIAMOND BRAND is especially recommended for

COLD ROLL THREADING,
TRIMMING AND
BLANKING DIES

and for all intricate cutting tools where NON-DEFORMATION is essential.

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Your Confidence

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CHEMICALS AND SERVICE

for SURFACE HARDENING *and* HEAT TREATMENT *of* STEEL

We are Headquarters for all Cyanide Compounds used in this line, including specially prepared mixtures of various strengths

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Equivalent in strength to 128/130% KCN

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} granular or lumps

Send for our booklet giving comprehensive data, and put your problems up to our technical staff for solution.

The **ROESSLER & HASSLACHER CHEMICAL CO.**

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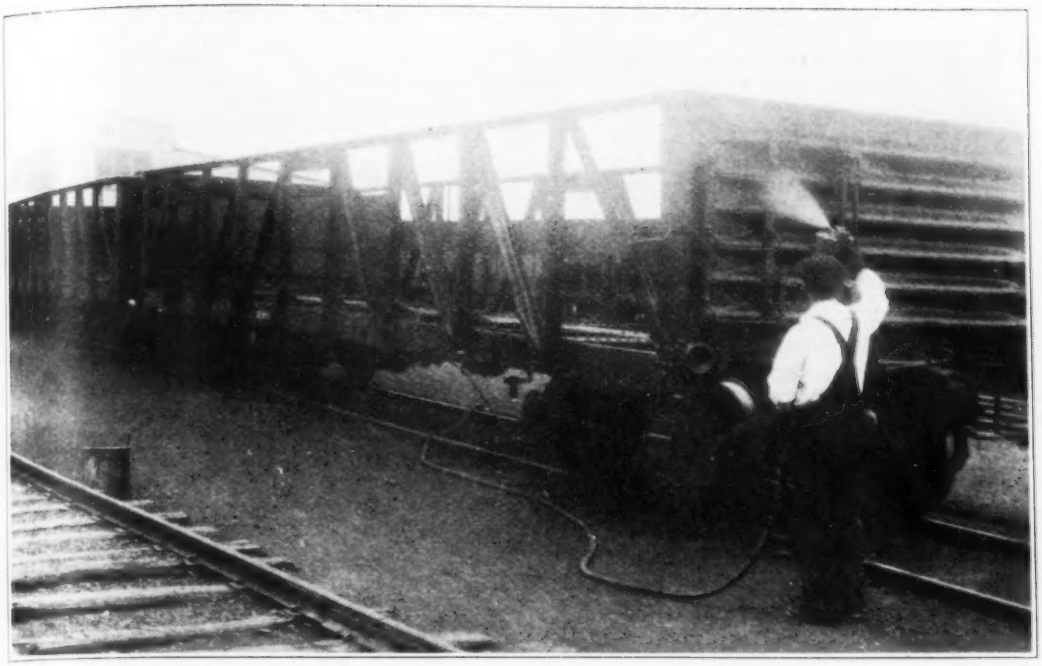

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IRON + OX = RUST
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AMERICAN SOCIETY *for* STEEL TREATING

The object of the Society shall be to promote the arts and sciences connected with either the manufacture or treatment of metals, or both.—Constitution A. S. S. T., Art. II.

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The Board of Directors of the American Society for Steel Treating has established a fund to be known as the Henry Marion Howe Medal Fund, the proceeds of which shall be used annually to award a gold medal to be known as the Henry Marion Howe Medal. The award will be made as follows:

(1) The medal will be awarded to the author of the paper which shall be judged to be of the highest merit. All papers in order to be considered must be published originally in the TRANSACTIONS of the Society during the twelve months ending August 1st of the year in which the medal is awarded.
(2) The competition for the Henry Marion Howe Medal shall be open to all.
(3) The award shall be made by the Board of Directors.
(4) The award may be withheld at the discretion of the Board of Directors.

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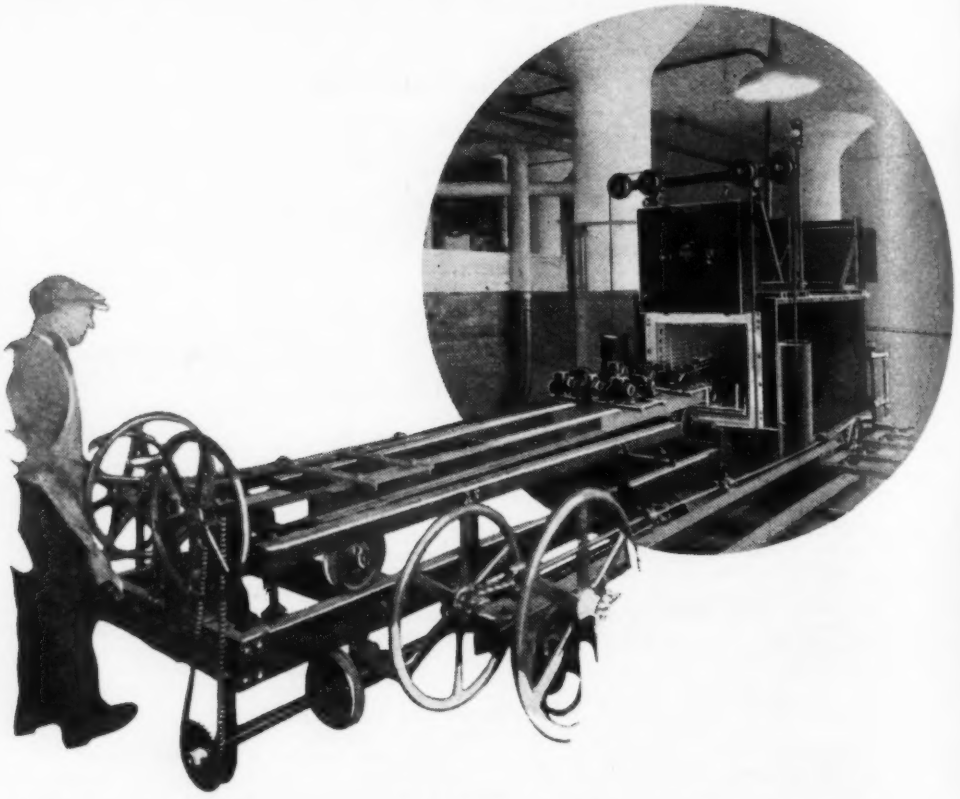

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These facts show what almost always happens when a Hoskins Electric Furnace is used on a job, that it fits. Whatever your heat treatment problem is, some one of Hoskins Electric Furnaces will help you solve it. Ask for Catalog 51-S.

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Originators and Manufacturers of **Chromel** The Alloy that made Electric Heat Possible

Q=ALLOYS

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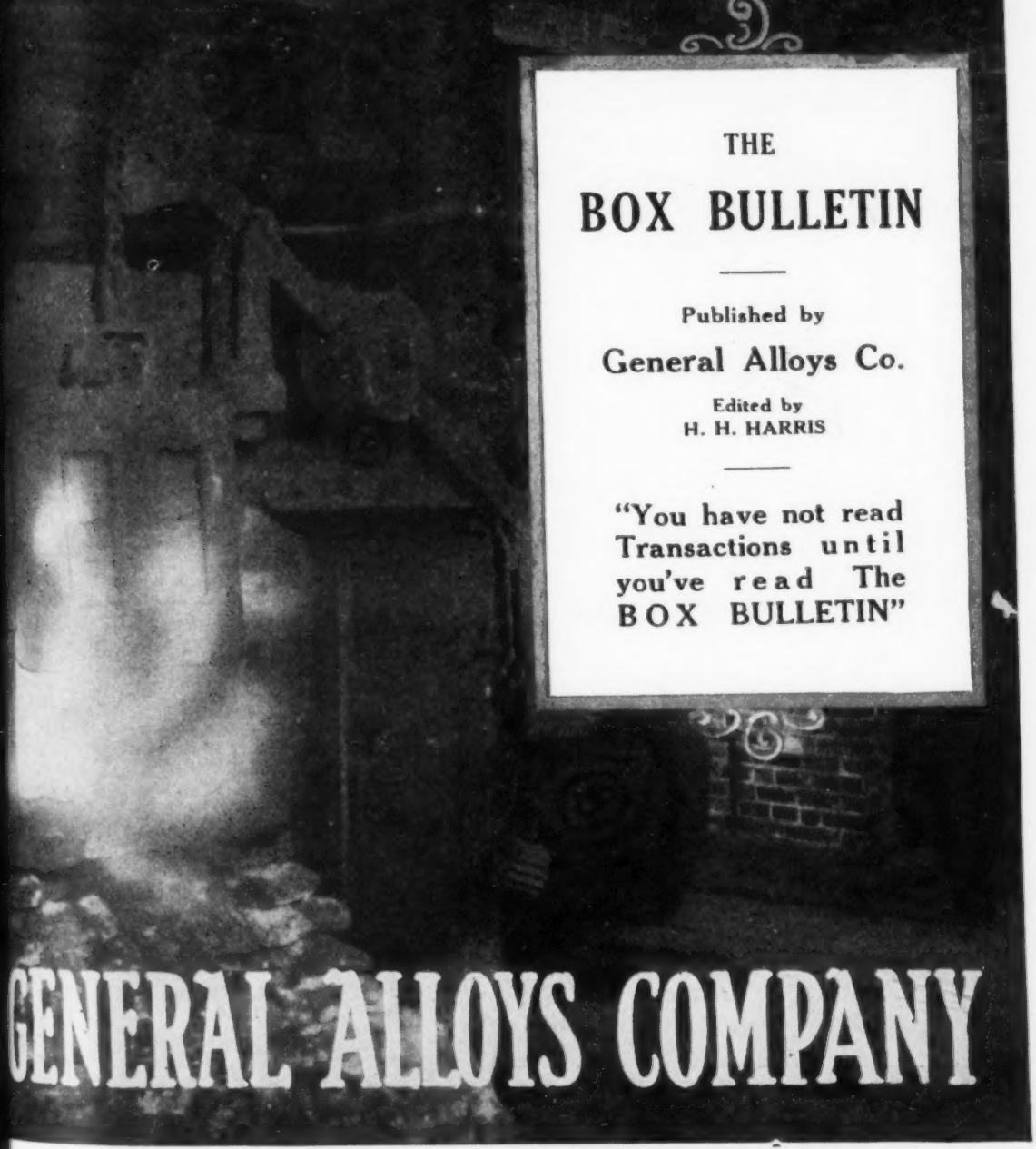


THE

BOX BULLETIN

Published by

General Alloys Co.

Edited by
H. H. HARRIS

"You have not read Transactions until you've read The BOX BULLETIN"

GENERAL ALLOYS COMPANY

When writing to General Alloys Company please mention TRANSACTIONS

Christmas Greetings!

May this Christmas be for you one of glory and gladness! May true happiness come to those most dear to you! May the incoming year greet you with prosperity in abundance! May every dawn bring with it some new delight for you! May every morning add to your joys, and every evening bring you peace and contentment!

General Alloys Company

BOSTON CHRISTMAS 1926

BOX BULLETIN SUPPLEMENT PAGE III

THE BOX BULLETIN

Lest Your Foot May Slip,-
in buying Electric Furnaces

THERE is a tremendous volume of Electric Furnace Business now being placed, and due for placing in the first quarter of the new year. We are flooded with Furnace Parts orders, and planning for more. The lessons that we have learned in Foundry Practice, Design, Testing, Etc., are being applied to the improvement of our product, yet:—

THE BIGGEST LESSON WE HAVE LEARNED FROM OUR CONTACT WITH FURNACE BUILDERS AND USERS, has little to do with alloy,—But IS OF VITAL IMPORTANCE TO YOU IF YOU BUY FURNACES.

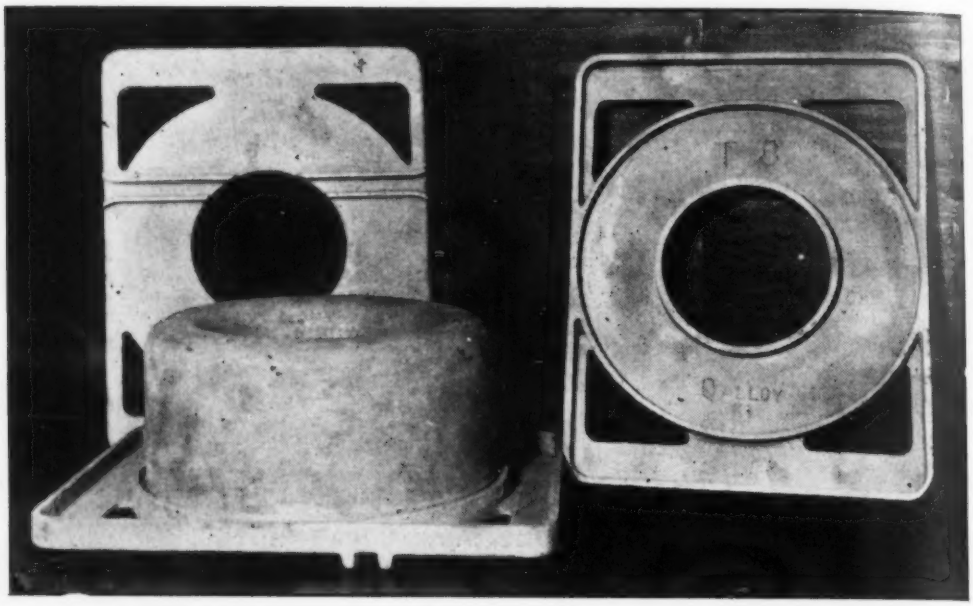
Here it is:

1. The best furnace built is not perfect
2. The best furnace built would be better and last years longer if the builder did not have to "Build to a price"
3. Further, and essential, approximation to perfection in furnace building is possible only when the buyer makes an INTELLIGENT FLEXIBLE APPROPRIATION to cover his needs.

Furnace building is a new art as now practiced, it has inherent limitations, the limitations of the existing practical knowledge. The man who adds additional limitations by driving the furnace builder, who must eat, to extremes of economy by buying Cheap Furnaces is *perforating his own parachute.* He is ruining his own chances of getting the best furnace obtainable.

Economy in first cost buying has its virtues, when applied to materials on which the buyer is thoroughly informed. As a rapidly progressing art the Builder of Furnaces knows so much more about his business than ninety-nine per cent of the plant Engineers, that the man who tries to tell the supplier how to build the furnace is getting on thin ice. In effect he tells him how to build it when he buys "On Price", which means that the maker must "Skimp" on the furnace.

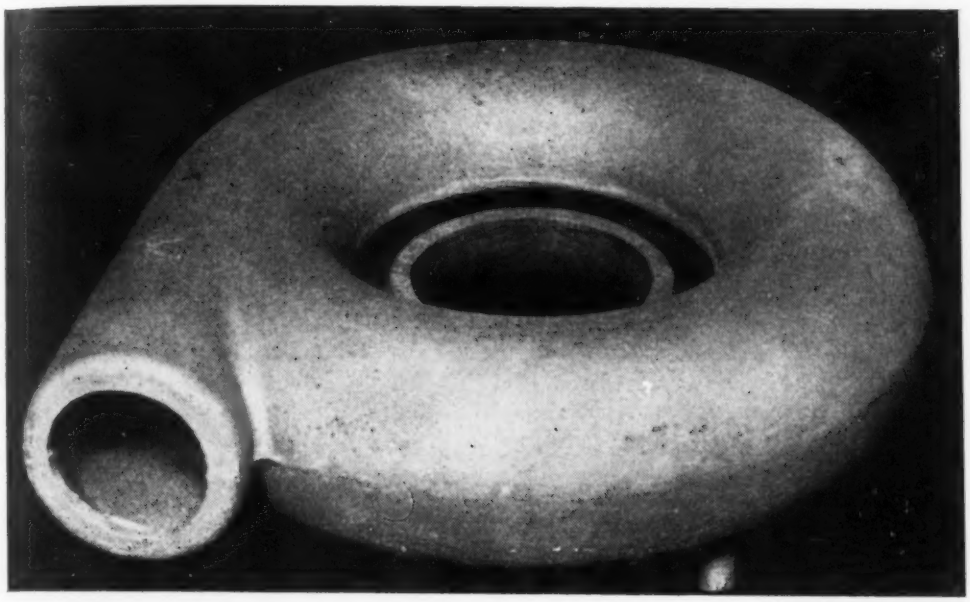
The Furnaces that are being taken out today, the ones that will be taken out in the future, are for the most part "Skimped" furnaces. Even on the Skimped ones the buyer often gets more than he's entitled to if he allowed the Builder half the margin he runs his own business on.



Large Pots Push Perfectly

THAT'S our verdict on the problem of pushing large Carbonizing or annealing pots through a Pusher, or Counter-Flow Furnace. Q-Alloy Trays, with Inverted Pots, relieve all strain from the Pot and insure the user of securing the economies pictured by the Furnace Engineer. We are making large numbers of exceptionally large pots and they are giving universal satisfaction. Your pot problem can undoubtedly be solved with Q-Alloy.

We have made more Pusher Pots, Boxes, and Trays than all other alloy makers combined, and it is only obvious that we should have learned something about them. What we have learned represents the difference between success and failure with pusher pots and boxes. Let one of our men explain that difference to you.

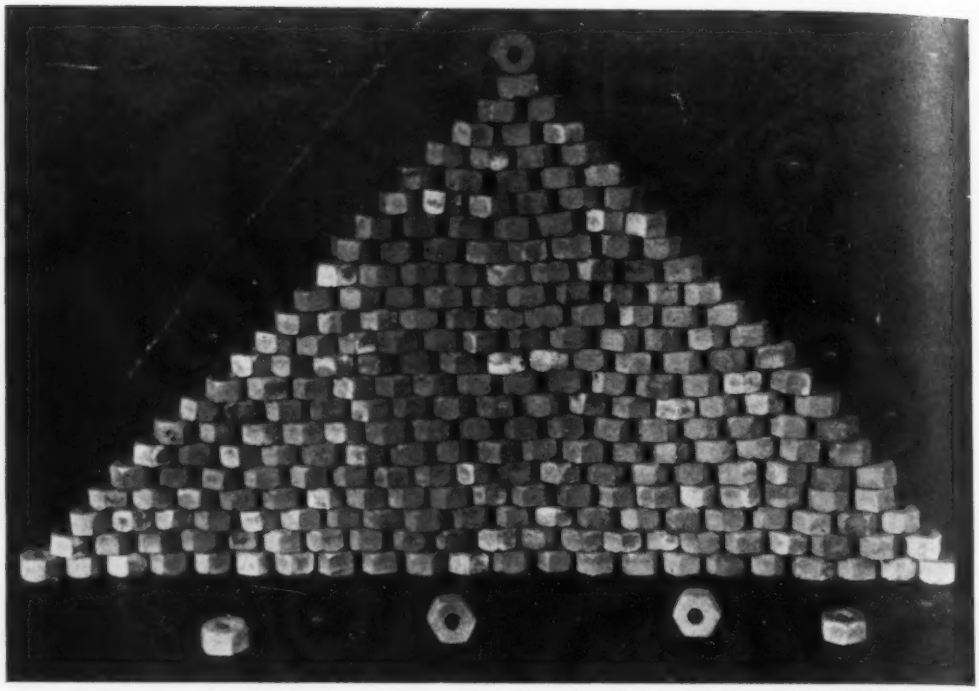


From Their Failures We Have Learned

THE gross and pitiable failures which many alloy makers have made and are making in the domestic oil burner field are so obvious that no one could fail to note them, particularly one studying the art.

We have made a lot of progress in our own development of domestic oil-burner fire pots, but we could not have progressed so rapidly without fostering a lot of bum stuff on the public, we never do that, had not our esteemed contemporaries made hundreds of alloy castings which *failed.*

From their failures we have profited. If you too can profit from your failures with other alloys, your experience with them may make you a customer of ours. To our contemporaries we are thus deeply obligated.



Nuts for Christmas

SOME enterprising Furnace Builder is going to get a flock of nuts that won't crack for the Holidays. This neat little pile is part of an order for several thousand, and of course there's the bolts to go with them. The bolts are heavy long ones and the boys thought it would save a lot of elbow grease just to show the nuts without the bolts.

Each of these nuts, when tapped and threaded, (and that's easy with Q-Alloy), will assume a lot of responsibility in proportion to its size —almost as much as a safety-pin. Little parts like these must be made to pattern,—sharp corners like their forged cousins, so that the wrench won't slip and bark the knuckles of the assemblying genii.

The whole meat of this nut situation is this. "Cheap" alloy foundries can't make neat castings like these. If they made them you couldn't machine them. These reasons, plus Q-Alloy quality, are good selling arguments

Historical Research

"YOU can just tell she wears 'em" remarked one Gladiator leaning on a Hot-Dog stand outside the great coliseum to his boy friend as Soldiers led a Christian Slave in clanking Chains into the arena. The Chain first functioned under heat at the Human Bar-B-cues of the Ancient World. Spirit communication fails to reveal exact temperatures. However, it's a safe guess that the first really satisfactory Chain for high temperature uses was Q-Alloy.

Tons of Q-Alloy chain have been supplied to serve under varying conditions of load under temperatures to 2000°F., and the service complaints have been few. Too many perhaps, both of them, but we are doing our best to surpass malleable foundries, who make chain by the hundred million links, with an alloy whose pouring characteristics are necessarily far more complex.

We will make better chain, but the chain we now make is about 96% commercially strong checking up all installations. Is your product any nearer perfection?

Q-ALLOYS

STAND UP UNDER FIRE

Q-ALLOYS

Most Economical and Efficient Materials

For CARBONIZING BOXES
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CYANIDE AND LEAD POTS
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operating between 1000° F. and 2200° F.

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Metallurgy of Iron and Steel

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By Birger Egeberg, metallurgist, Halcomb Steel Co., Syracuse, N. Y.

TABLE OF CONTENTS

Chapter I—Manufacture of Iron and Steel
Chapter II—Mechanical Treatment of Steel
Chapter III—Manufacture of Iron and Steel Castings
Chapter IV—Wrought Iron, Malleable Iron and Semi-Steel
Chapter V—Chemistry of Iron and Steel
Chapter VI—Chemistry of the Blast Furnace and Bessemer Process
Chapter VII—Chemistry of the Open-Hearth and Electric Furnace Processes of Steelmaking
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by W. TRINKS

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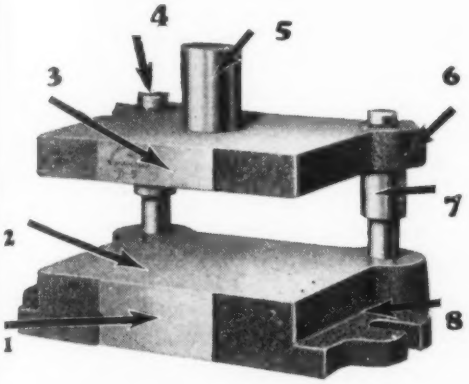
they say.

"A new Standard of performance"

is how we express it.



1. **Rapid and accurate set-up,** front and rear of die shoe and punch holder machined parallel to leader pins and bushings.
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8. **Rapid and rigid set-up** under all requirements, because of ample clamping surface or slotted ears.

Yes, Danly Die Sets are strictly precision tools.

YES, it does seem hardly believable that a steel can produce 350,000 pieces between grinds when at one time it could never produce more than 10,000. Yet this is typical of the result of mounting dies in Danly Die Sets—"hardly believable" increase in the life of dies, with many other advantages.

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AMERICAN SOCIETY FOR STEEL TREATING
4600 Prospect Ave. **Cleveland, O.**

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4600 Prospect Ave., Cleveland, Ohio
(See opposite page for Classification and rate for dues.)

I hereby make application for (*Member Junior / Associate Sustaining*) ***membership in the Society,*** *and* ***agree, if elected, that I will be governed by the Constitution, By-Laws and Rules of the Society as long as I continue a member.*** *I furthermore agree to promote the objects of the Society so far as it shall be in my power.* ***$5.00 of my dues is*** *for one year's subscription to The Transactions of the American Society for Steel Treating.*

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American Society for Steel Treating

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Dues $10.00 per annum.

(d) "An ASSOCIATE shall be a person, at least twenty-one years of age, who is engaged in work related to the manufacture or treatment of metals, or the arts connected therewith, and who is a member of the sales department of an organization which manufactures or deals in materials, supplies or equipment used in such arts."
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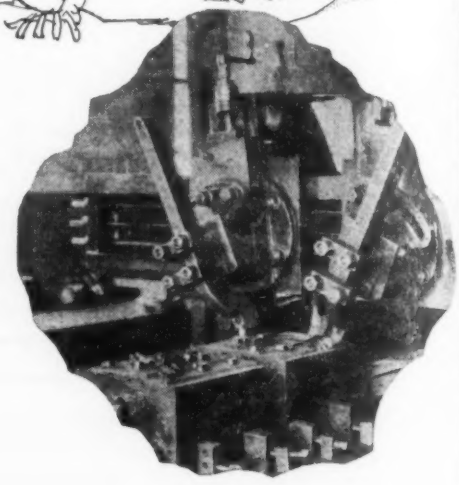
All dues are payable immediately upon notification of election to membership and are for one year from date of said election. Following payments are due upon same date each year.

If a member desires, his dues may be paid in two equal installments.

The Survival of the Fittest



EVER since the dawn of history the law of life has been the survival of the fittest. ¶ Recently in the wonderful plant in which is produced one of the finest motor cars made in America—the

LOCOMOBILE

—a blind test was conducted to determine the make of tool steel they should adopt for production work on lathes and shapers. Each tool was treated exactly as instructed by the steel manufacturer. The tools were then designated by number only, so that the machine operators had no way of discriminating between the various makes. Each steel was given a break-down test,—on the basis of these blind tests—Locomobile has standardized on Red Cut Superior High Speed Steel.

Vanadium-Alloys Steel Company

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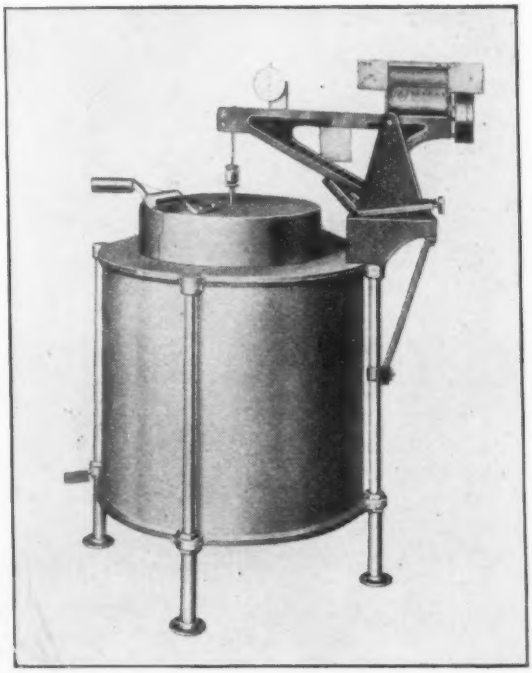
"Hasn't Cracked A Die Yet"



YES, we will admit it's a bold statement but nevertheless of the thousands of dies, tools, gears, etc., heat-treated by the VOLCRIT (volume-critical) method using the ROCKWELL DILATOMETER we have yet to hear of one cracked in heat-treatment. And better still, these VOLCRIT treated parts are all giving greater service and life than was hitherto thought possible.

Better investigate now and reduce that scrap pile of "cracked in heat-treatment" parts.

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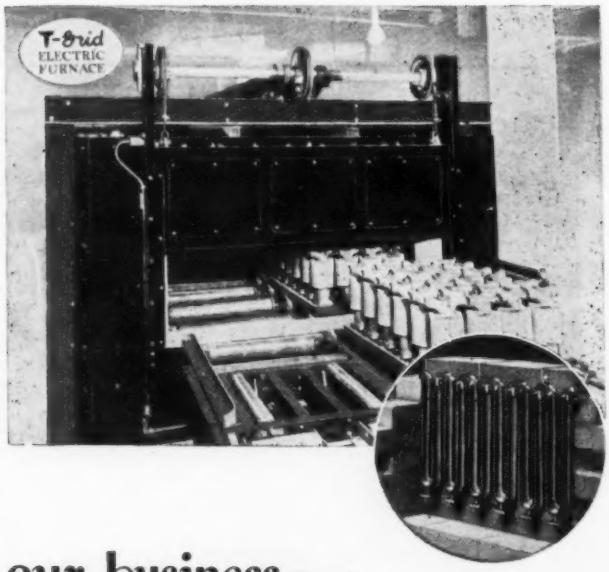

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Whatever may be your heat treating problem, T-Grid engineers will give competent advice in selecting the best furnace type, and in the planning of auxiliary equipment. T-Grid furnace designs covering every type and size, and a wide range of auxiliary handling, timing, and quenching equipment, insure complete solution of every need.

Both T-Grid Electric Furnaces and their auxiliaries are built on the same standard of ruggedness, dependability, and correct design, which have kept T-Grid equipment at the front in the heat treating field.

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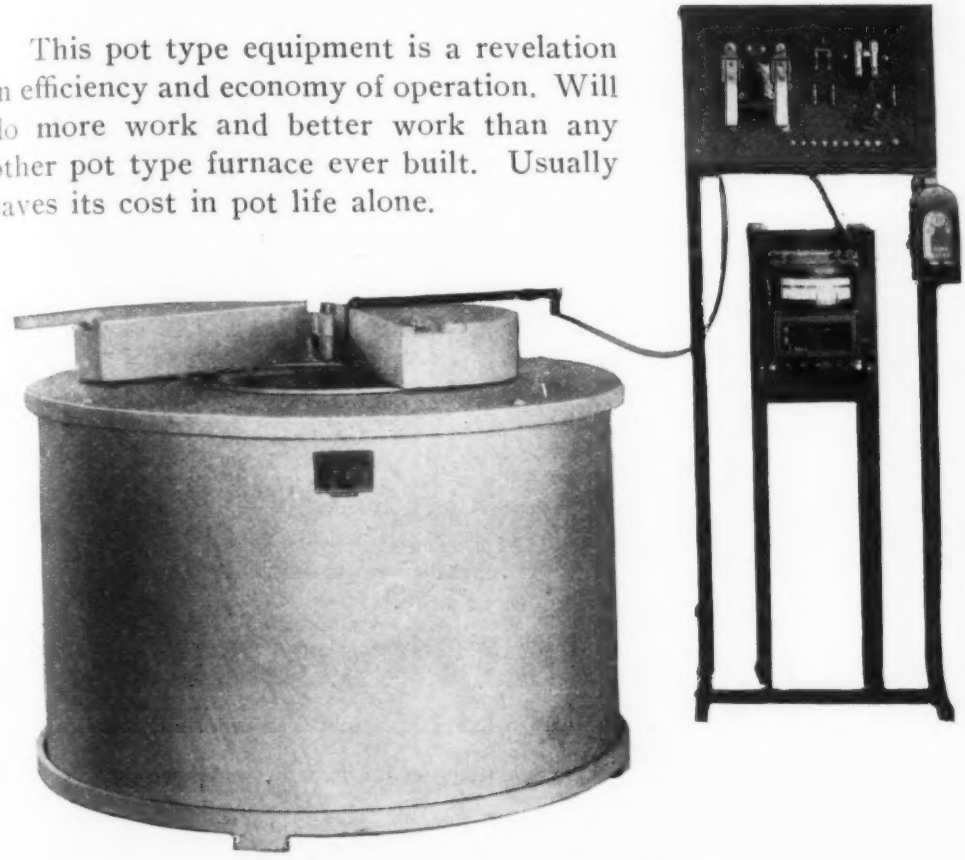
for LEAD—CYANIDE—SALT—BABBITT—ALUMINUM.

This pot type equipment is a revelation in efficiency and economy of operation. Will do more work and better work than any other pot type furnace ever built. Usually saves its cost in pot life alone.



Temperature range to 1700° F.

These furnaces have completely solved the question of getting the most heat per unit of current consumption and wherever a lead, salt or cyanide furnace is used, the "AMERICAN" ELECTRIC will show enormous savings in labor, quality and work produced.

We shall be glad to recommend the right furnace for your work.

American Metallurgical Corporation

27 VON HILLERN STREET

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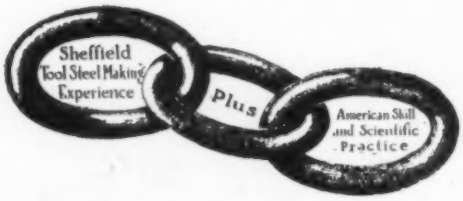
AMERICAN

"JESSOP'S"
TOOL STEEL



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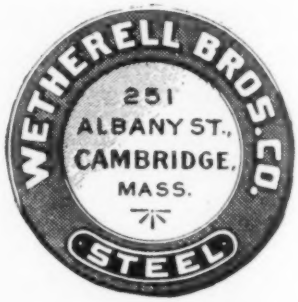
TOOL STEEL
BARS SHEETS
BLOCKS



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WE ESPECIALLY RECOMMEND THIS GRADE FOR TOOLS REQUIRING A KEEN, DURABLE CUTTING EDGE, SUCH AS TAPS, REAMERS, THREADING DIES, BLANKING, PUNCHING, FORMING, AND TRIMMING DIES, MASTER TOOLS, GAUGES, AND FOR ALL PURPOSES WHERE TOUGHNESS, NON-SHRINKING, NON-DISTORTION QUALITIES ARE REQUIRED.

ZIV STEEL & WIRE CO.

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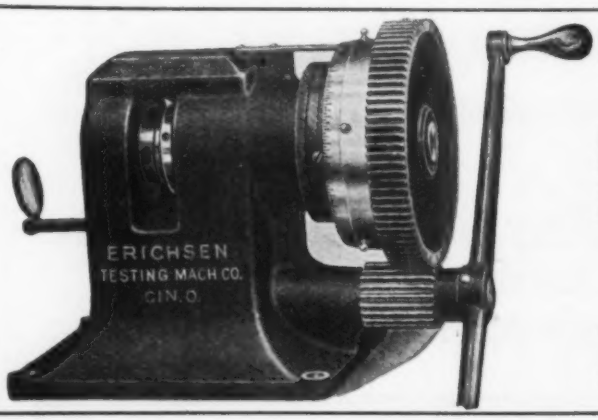

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For the Determination of the Drawing, Stamping, Compressive and Folding Qualities (the "Workability") of Sheet Metals.

Know your Metal.
Save time and save money.

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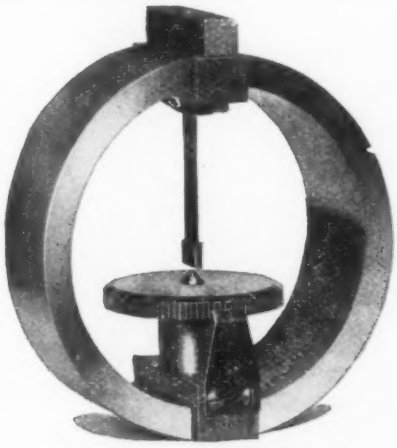

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Hardness Testing Machines.
Bureau of Standards
Certificate of Calibration
With each of Our Instruments;
Proof of Excellence,
Mark of Distinction.

Morehouse Machine Co.
YORK, PA.

Stuart Oils
FOR THE "TOUGHEST" METAL WORKING CONDITIONS

New Development In BROACHING OIL

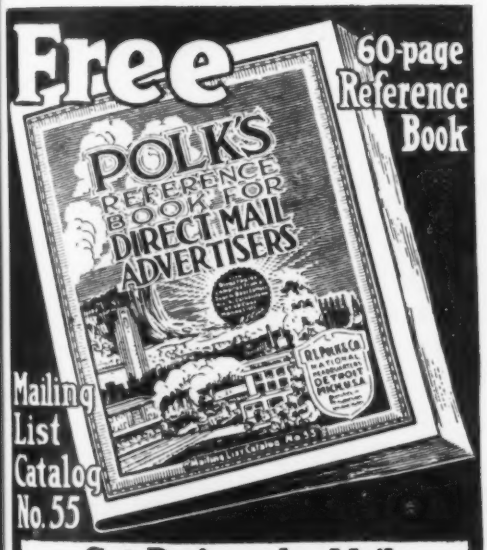
The new STUART Broaching Oil successfully eliminates the necessity for white lead, lard oil or costly sulphur base oil mixtures. It produces a glass-like finish on the tough alloy steels usually specified for automotive gears and allows broaching speeds up to 30 feet per minute.

Compared with "home-made" broaching oil mixtures the STUART product in ready-mixed form offers EIGHT specific advantages carefully described in the new STUART booklet on the subject of broaching oil.

Write for Your Copy at Once.

D.A.STUART & CO.
ESTABLISHED 1865
CHICAGO. U.S.A.
Warehouses in Principal Centers

Free 60-page Reference Book



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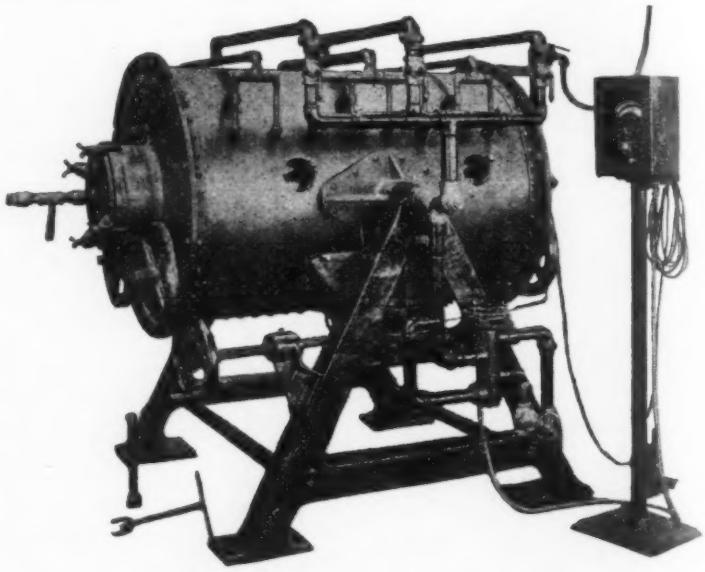
Another Furnace Installation
BY THE
LORD ELECTRIC CO.
112 WATER STREET
NEW YORK BOSTON PITTSBURGH

An 8"x24" rectangular electric lead pot for heating rock drills for forging Edison Electric Illuminating Co. Boston



No. 2-B carbonizing machine with heat controller. Capacity about 600 lbs. per charge.

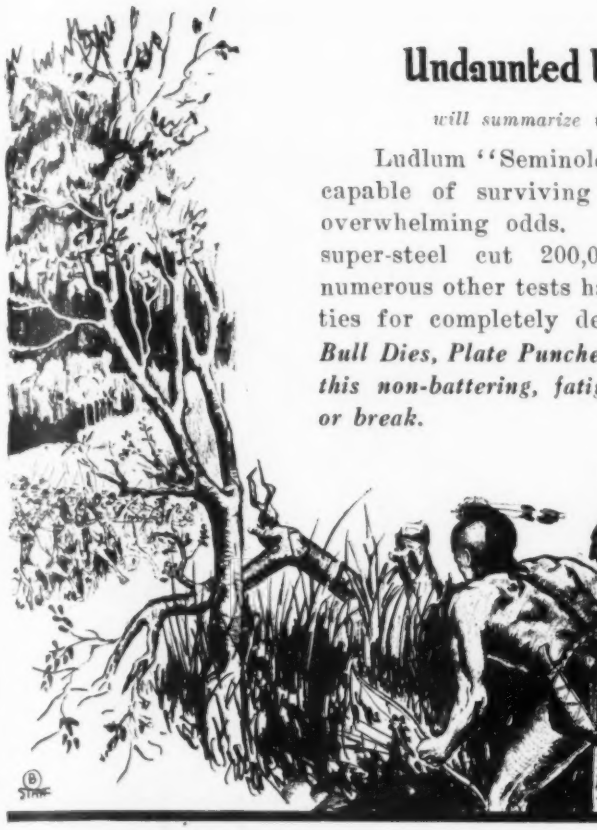
900% Net Return On Gas Carburizing

ONE of the largest manufacturers of coal mining machinery formerly used liquid fuel for carburizing and heat treating steel. American Rotary Gas Carburizing Machines were recommended and installed. During the first normal month's operation with this equipment, in which time 113 tons of steel were carburized and heat treated, costs were reduced from $115.00 to $47.50 per ton. During August, 1926, 213 tons were processed (carburized and heat treated in the same machines) at a cost of approximately $27.00 per ton. Not allowing for depreciation of equipment, which is less than 10% each year, these figures indicate a net saving and return on investment of 900%.

Bulletin 12-A On Request

AMERICAN GAS FURNACE CO.

ELIZABETH, N. J.



Undaunted by Overwhelming Odds

will summarize the characteristics of the Seminoles.

Ludlum "Seminole" Heavy Duty Chisel Steel is no less capable of surviving the hardest of punishment against overwhelming odds. For example, a chisel made of this super-steel cut 200,000 rivets without breaking while numerous other tests have proven its superior enduring qualities for completely defying the heavy usage demanded of ***Bull Dies, Plate Punches and Dies—Let us tell you more about this non-battering, fatigue resisting steel that will not crack or break.***

LUDLUM STEEL CO.

Watervliet, N. Y.

LUDLUM

SEMINOLE

UNBREAKABLE HEAVY DUTY CHISEL STEEL

For better results in heat treating—

valuable suggestions in this FREE book

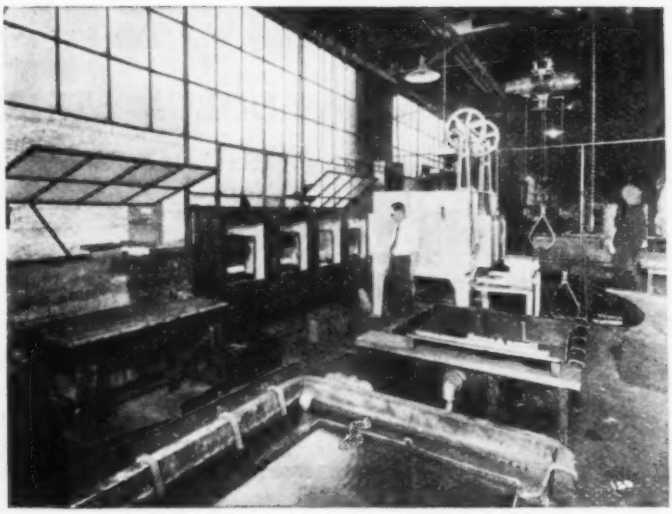
A practical and concise treatise on the problems of quenching and their successful solution has been published for free distribution by The Griscom-Russell Company. This treatise briefly outlines the principles of heat-treatment operations in general, explains the factors that must be considered in determining the correct quenching speed, fully discusses the various quenching mediums with their applications and limitations, and explains the methods by which Ford, Packard, General Motors, Hyatt, Ingersoll-Rand and many other concerns are securing uniformly excellent results in their quenching operations.

For your free copy, write to

The Griscom-Russell Co. Dept. G, 285 Madison Ave., New York

Another Installation of

HEVI DUTY FURNACES



at

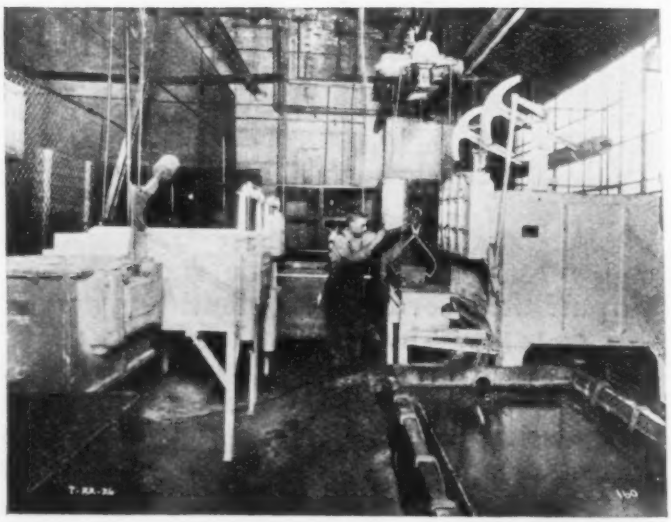
Great Lakes Forge Co.

Chicago

This is one of a series of advertisements showing how owners of Hevi Duty furnaces specify Hevi Duty for additional equipment.

The above furnace was installed in April of this year. The three furnaces at the right were added as a result of the successful operation of the first.

"100% satisfactory," advises A. M. Steever, chief metallurgist.



HEVI DUTY ELECTRIC CO.

MILWAUKEE, WIS.

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When writing to Hevi Duty Electric Co., please mention TRANSACTIONS

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HEAT TREATED
PRODUCTS
OUR SPECIALTY

Heppenstall Forge & Knife Co.

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TOOL STEEL

FINE STEELS
MADE BY THE
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CLARITE HIGH SPEED STEEL
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It pays to use Good Tool Steel.

COLUMBIA TOOL STEEL COMPANY
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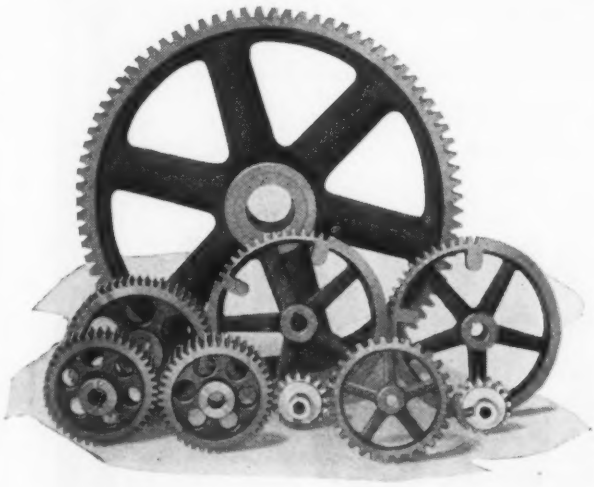

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Any size or kind. We have the most complete facilities in the Middle West. Write our nearest office.

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IT IS equally important to know the proper steel to order and to know that you will get what you order—exactly. Interstate experienced metallurgists and Interstate precise manufacture will help you make sure of both.

INTERSTATE IRON & STEEL CO.
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CHICAGO

Interstate Steels

Open Hearth Alloy Steel Ingots, Billets, Bars
Wire Rods, Wire, Nails, Rivets and Cut Tacks
Iron Bars and Railroad Tie Plates

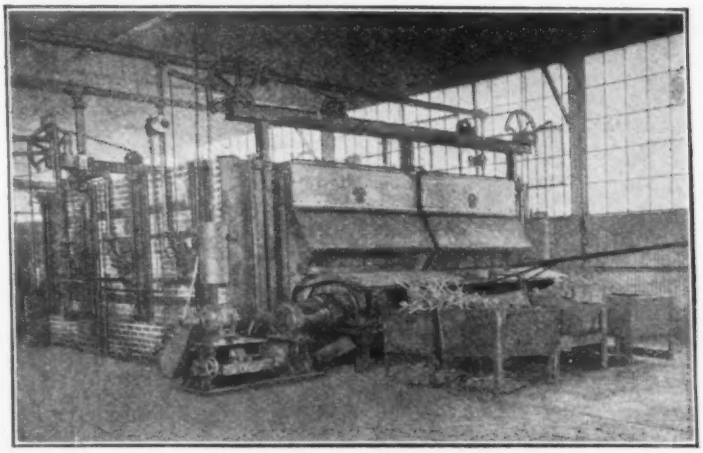
When writing to Interstate Iron & Steel Co., please mention TRANSACTIONS

ROCKWELL

ELECTRIC AND FUEL FURNACES

For HEAT-TREATING

AUTOMATIC, SEMI-AUTOMATIC And STATIONARY TYPES



AUTOMATIC HEAT-TREATING FURNACE

FURNACES and fuels should be selected for the useful service they can render when properly employed under specific conditions, and with due regard to their form as well as price. Each should be selected on its merits. Their use is but a means to an end, the **economic value of which is measured by the resulting quality and cost of the finished product or service,** and not by any one phase of their performance.

We are free from prejudice or preference in the matter of fuel or electricity, or type of furnace equipment, as our aim is to deal with each case on its merits.

Bulletin 234-C illustrates methods of heating and handling and furnaces employed in a great variety of heat-treating operations.

Write nearest office for a Copy

W. S. ROCKWELL COMPANY

FURNACE ENGINEERS and CONTRACTORS

50 Church St. **(Hudson Terminal Building)** **New York**

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Montreal, Canada: 358 Beaver Hall Square.

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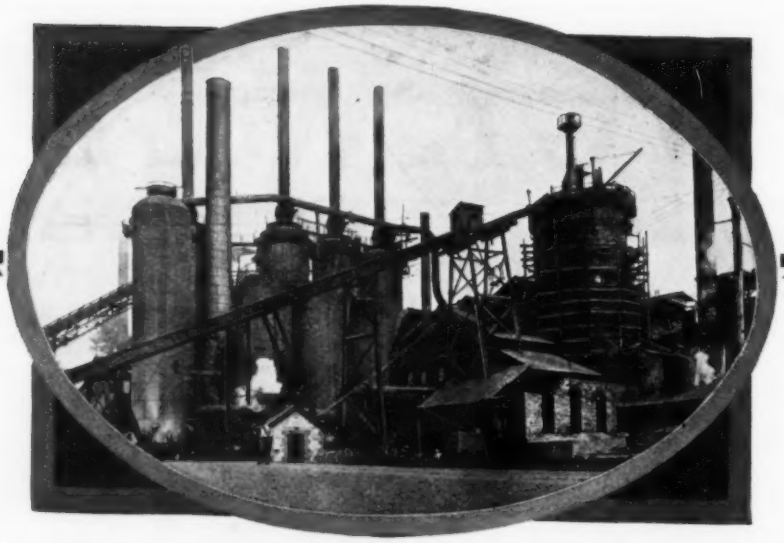

Blast Furnace Operators need this data!

A LEADING firm of blast furnace engineers has compiled a list of temperature and pressure measuring instrument applications which have proven practical and profitable in blast furnace operation. Those suggested are tabulated below. Let us supplement them with definite recommendations. Simply check the items that interest you and send us this advertisement.

INSTRUMENT	APPLICATION
Pyrometer	Hot blast main at entrance to bustle pipe.
	Downcomer, or top dustcatcher.
	Stove flues.
Pressure Gauge	Blast pressure in hot blast main after washer.
	Blast pressure short valve wheel.
	Blast pressure near blowers.
	Water pressure in bosh water circle pipe.
Thermometer	Temperatures of incoming washer water.
	Temperatures of discharge water.
	Temperature of cleaned gas.
Flow Meter	Gas flow in stove main.
	Flow of washer water.
	Air (blast) flow.

For Power Plant

INSTRUMENT	APPLICATION
Pyrometer	Boiler flue gas temperature.
Thermometer	Temperature of condenser water at inlet and outlet.
	Steam temperature.
Pressure Gauge	Steam pressure.
	Blast pressure at blowing engine.
Flow Meter	Steam flow from individual boilers.
	Steam flow on steam distribution lines.

"To Measure is to Economize"—Pascal.

THE BROWN INSTRUMENT COMPANY, 4557 Wayne Avenue, Philadelphia, Pa. District offices: New York, Boston, Pittsburgh, Detroit, Cleveland, Columbus, Chicago, Indianapolis, Birmingham, Houston, El Paso, Tulsa, St. Louis, Denver, Salt Lake City, San Francisco, Los Angeles, Montreal.

Brown Instruments

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Pure Cobalt
Ferro Titanium
Calcium Silicon
Tungsten (Powder & Ferro)
And Other Special Alloys

Large stocks carried in New York

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Metallurgical Engineers

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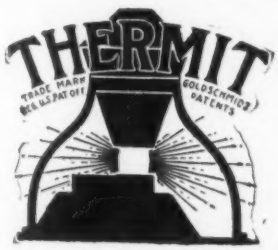
Vulcan
TOOL STEEL

When up against it—
use Vulcan

Vulcan Crucible Steel Co.
Aliquippa, Pa.



Automobile and other Alloy Steel Specifications are becoming more and more exacting

It is necessary, therefore, to use the highest grade of raw materials entering into the construction of automobiles, machine parts, etc.

In the manufacture of our various metals and alloys, we must use, and do use, the highest grade of ores, oxides and aluminum.

Tungsten Powder	97-98%	Pure Chromium	97-98%
Pure Manganese	96-97%	Ferro-Tungsten	75-80%
Ferro-Chromium	60%	Ferro-Titanium	25%

Ferro-Vanadium 35-40% (1% Silicon)

Send for Pamphlet No. 2021

METAL & THERMIT CORPORATION

Pittsburgh
Chicago
Boston

120 Broadway, New York City

S. San Francisco
Toronto

LIST OF A. S. S. T. DATA SHEETS

The following data sheets have been issued and sent to members. New members desiring back sheets may order all or any sheets desired at the "rate to members." Members will receive free data sheets as issued during the period of their membership.

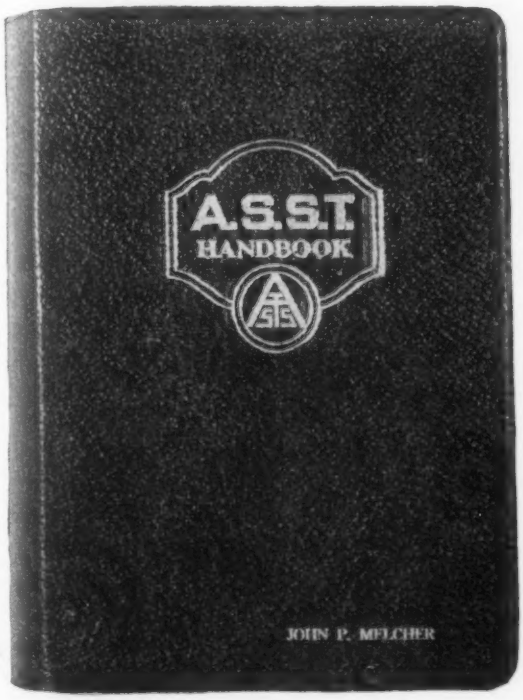
Send all orders to A. S. S. T., 4600 PROSPECT AVE., CLEVELAND, O.

	Page No.	No. Sheets	Cost to Members	Cost to Non-Members
Nitrogen in Steel	A3-4	1	$0.05	$0.10
Melting Points of Chemical Elements / Fusing Points of Seger Cones	A5 / A6	1	.05	.10
Physical Constants of the Principal Alloy-Forming Elements	A6a, 6b, 6c	3	.15	.30
Decimal and Metric Equivalents of Parts of an Inch	A7-10	2	.10	.20
Specific Heat of Air	A11-14	2	.10	.20
Weights of Steel Bars / Wire Gauges	A15-22	4	.20	.40
Temperature Conversion Table	A23 and 24	1	.05	.10
Iron-Carbon Diagram	A25-38	7	.35	.70
Mass Influence in Heat Treatment	A39-42 Incl.	2	.10	.20
Interconversion Table for Units of Energy, Volume and Weight	A43-44	1	.05	.10
Corrosion of Iron and Steel	A45-50 Incl.	3	.15	.30
Abrasive Wheels for Grinding Steel	A51-73	12	.60	1.20
Metals and Ferro-Alloys used in the manufacture of Steel	A-75-84	5	.25	.50
Heat Content of Metals	A-85-90	1	.15	.30
Nickel and Nickel-Chromium Steels	C3-24	11	.55	1.10
Stainless Steel	D3-10 Incl.	4	.20	.40
Vanadium as an Alloying Element in Steel	F3-8	3	.15	.30
Tungsten as an Alloying Element in Steel	I1-4	2	.10	.20
Recommended Practice in the Heat Treatment of 18% Tungsten High Speed Steel	M3-4	1	.05	.10
Recommended Practice for the Heat Treatment of Plain Carbon Tool Steel	N3-6	2	.10	.20
Recommended Practice for the Heat Treatment of Non-Shrinking, Non-Deforming, Oil-Hardening Tool Steels	N7-8	1	.05	.10
Recommended Practice for the Heat Treatment of Finishing Steel	N9-10	1	.05	.10
Recommended Practice for the Heat Treatment of Taps and Milling Cutters	N11-14	2	.10	.20
Tool Steel Trade Names	N15-24	5	.25	.50
Carburizing and Heat Treatment of Carburized Steels	R3-R13	6	.30	.60
Recommended Practice for the Carburizing of Gears	R15-17	2	.10	.20
Recommended Practice for the Carburizing and Heat Treatment of Camshafts	R19-21	2	.10	.20
Carburizing Table	R-23-34	1	.05	.10
Pyrometry	S3-17	8	.40	.80
What Should a Man With only One Pyrometer Do in Case of Trouble	S-19-30	6	.30	.60
The Preparation of Metallographic Specimens	T3-6	2	.10	.20
Etching Solutions for Iron and Steel and the Structures Revealed by Each	T7-22	8	.40	.80
Photomicrography	T23-38 Incl.	8	.40	.80
Critical Illumination in Photomicrography	T39-42	2	.10	.20
Etching Solutions for Non-Ferrous Metals	T43-56	7	.35	.70
S. A. E. Steel Specifications	U3-6	2	.10	.20
Brinell Hardness Test	V1-2, 2a, 2b, 2c	3	.15	.30
Rockwell Hardness Test	V3-5	2	.10	.20
Scleroscope Hardness Test	V7-10	2	.10	.20
Percentage Reduction of Area for Tensile Test Specimens	V11-16 Incl.	3	.15	.30
Test Specimens	V17-29 Incl.	7	.35	.70

(Continued on Next Page)

LIST OF A. S. S. T. DATA SHEETS—*(Continued)*

	Page No.	No. Sheets	Cost to Members	Cost to Non-Members
Cutting Tests of Tool Steels	V31-43	7	.35	.70
Standard Clay Fire Brick Shapes and Tables for Turning Diameters with Standard Fire Brick Shapes	W1-20 Incl.	10	.50	1.00
Lead Baths	W21-35 Incl.	8	.40	.80
Fuel Consumption and Heat Losses	W37-42 Incl.	3	.15	.30
Determination of Electric Furnace Efficiencies and Heat Treating Costs	W43-50	4	.20	.40
Physical and Chemical Properties of Refractory Material	W51-68	18	.90	1.80
Recommended Practice for the Heat Treatment of Plain Carbon and Alloy Spring Steel	Y3-4	1	.05	.10
Heat Treatment of Permanent Magnet Steel	Y5-8	2	.10	.20



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DATA SHEET BINDER

The binder shown here is of genuine cowhide, with 1 inch rings, capacity 350 sheets and pocket in cover, especially made for A. S. S. T. Hand Book sheets.

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Members may obtain this binder, with name (in gold) stamped on cover for **$2.00.**

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American Society *for* Steel Treating

Cleveland, Ohio

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CARBURIZING COMPOUNDS

CLEAN — UNIFORM

HEAT TREATING SUPPLY COMPANY

SANDUSKY, OHIO

MAY WE HELP YOU?

If you want to improve your product ask us about the following.

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Kwick Kase (for cyaniding)
Lead Pot Carbon (for covering Lead Pots)
Tempering Oils
Tempering Salts (High and Low Temperatures)
Sodium Cyanide (96-98%)
Brinell Machines
Furnace Cements
Metal Cleaners
Platers Cleaners
Enamel Stripper
Detergents and Special Cleaners for all purposes
Copper & Zinc Cyanide
Nickel Salts (Single)

Rubbing and Finishing Compounds for all lacquers

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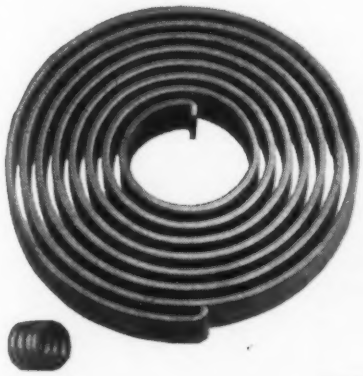

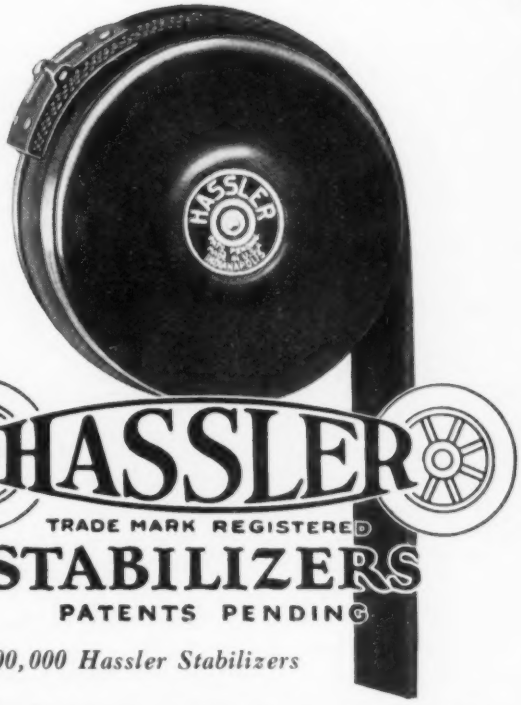

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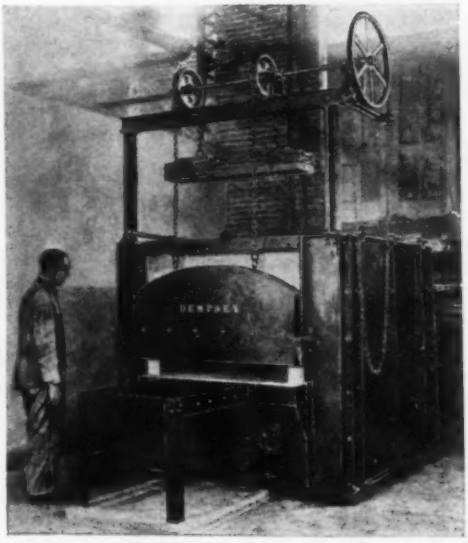

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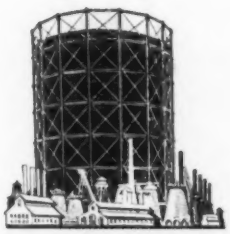

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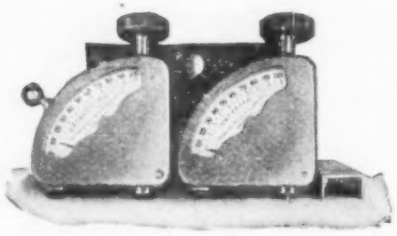

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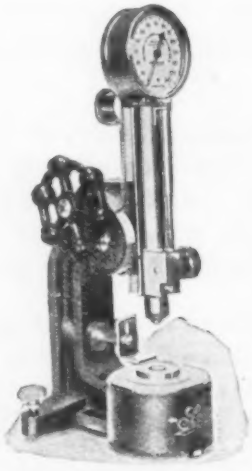

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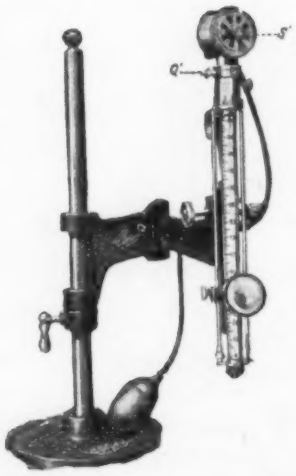

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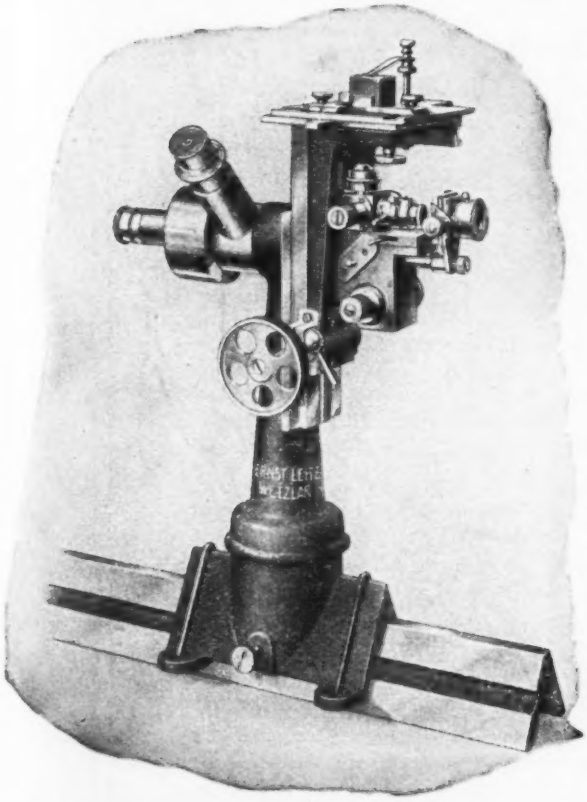

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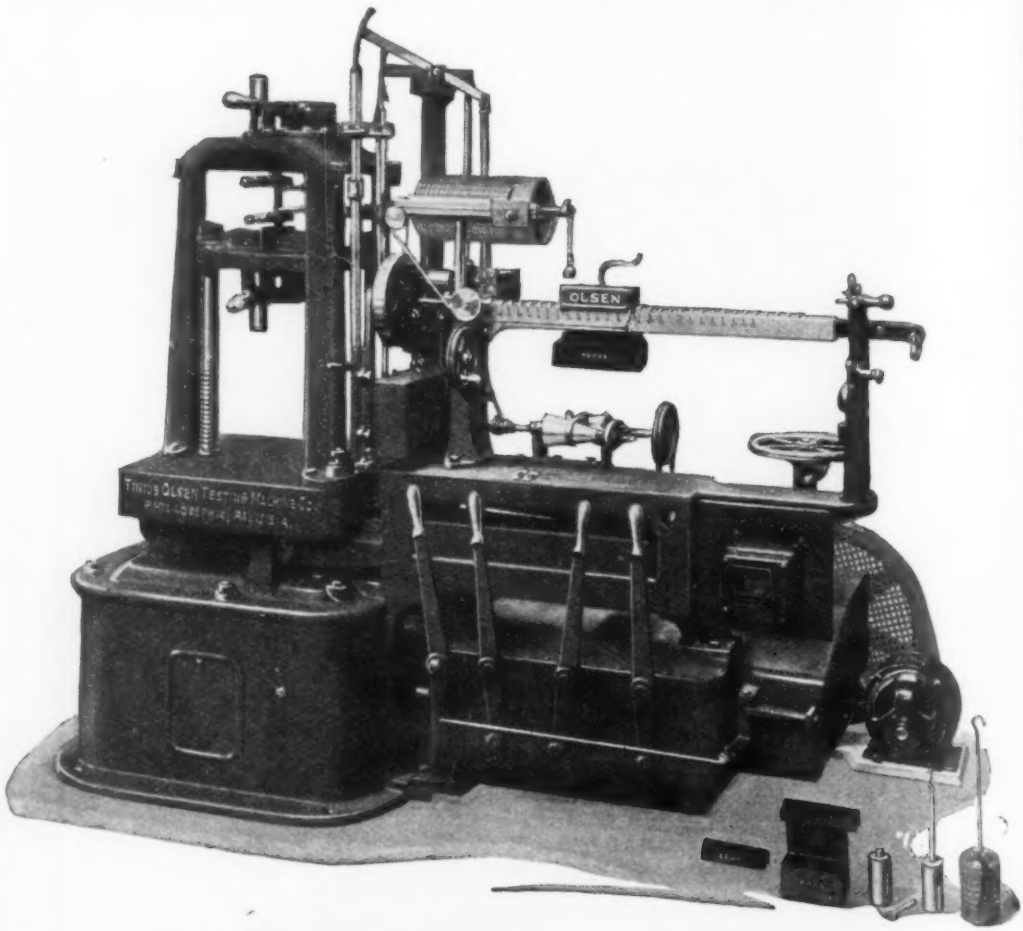

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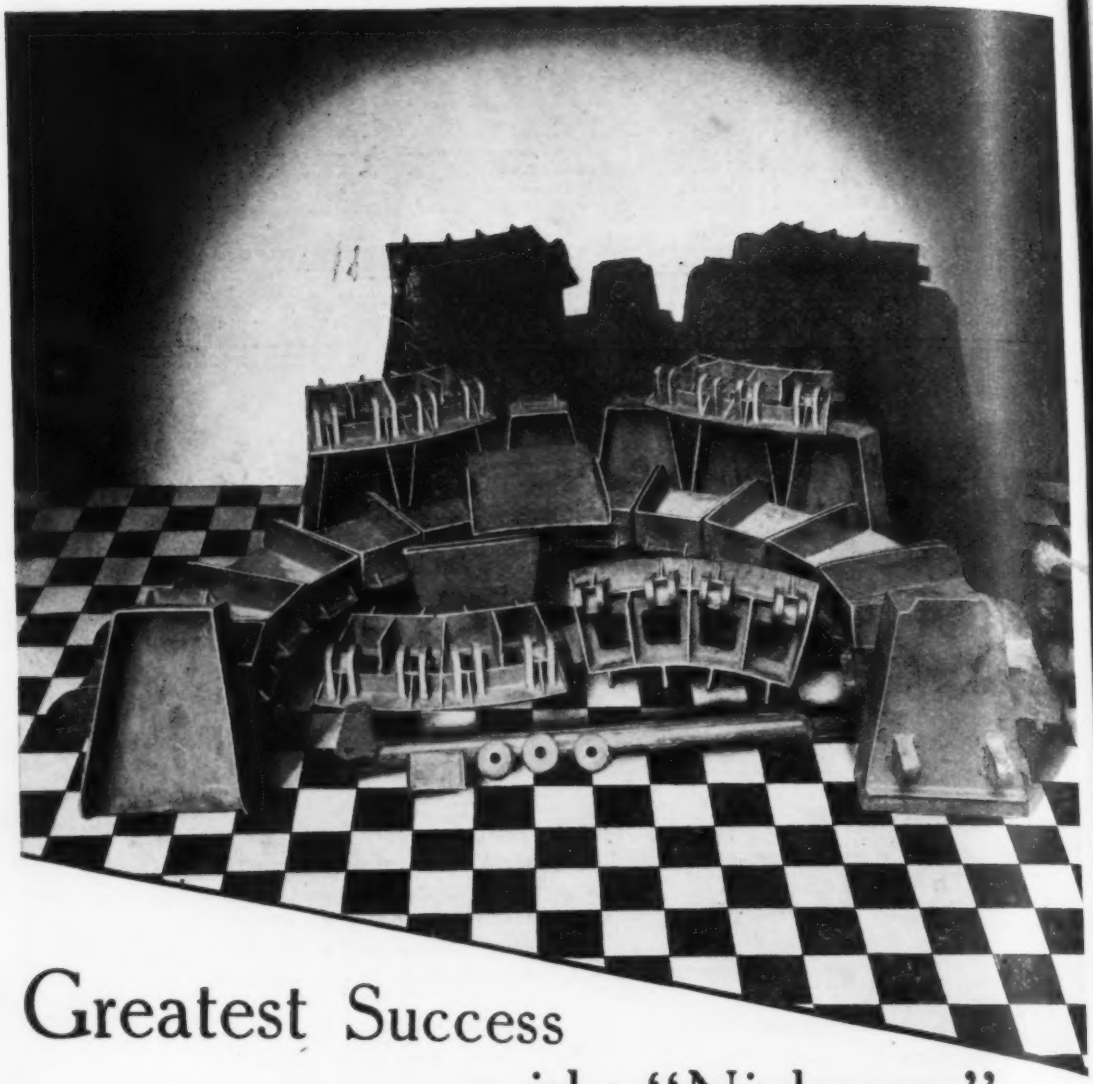

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